PREDICTIONS OF FIRE BEHAVIOR AND RESISTANCE TO CONTROL

FOR USE WITH PHOTO SERIES FOR THE SIERRA MIXED CONIFER TYPE AND THE SIERRA TRUE FIR TYPE

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Abstract

This publication presents tables on the behavior of fire and the resistance of fuels to control. The information is to be used with the photos in the publication, "Photo Series for Quantifying Forest Residues in the Sierra Mixed Conifer Type, Sierra True Fir Type" (USDA For. Serv. Gen. Tech. Rep. PNW-95, 1979, by Wayne G. Maxwell and Franklin R. Ward).

KEYWORDS: Fire behavior (forest), fire management, fire spread.

Metric Conversion

To change	to	multiply by:
Miles per hour	kilometers per hour	1.6093
Chains	meters	20.12
Feet	meters	0.3048
Acres	hectares	0.4047

Species List

Douglas-fir	*Pseudotsuga menziesii* (Mirb.) Franco
fir	*Abies* spp.
ponderosa pine	*Pinus ponderosa* Dougl. ex Laws.

windthrow, ice damage, and wildfire--often leave undesirable amounts of forest residues. The forest manager must set limits on the amount of residues and fire hazard that are consistent with resource management objectives.

Photo series have been published as an inventory tool to assess fuel loadings by size class in several forest types. The photos are used to translate visual images to quantities (tons per acre) so the manager can describe the residue that should be retained to meet environmental concerns and goals of a particular specialty. The photos also provide a starting point for assessing fire hazard.

This publication presents tables for predicting rate of fire spread, flame length, and resistance of fuel to control for each residue condition depicted by the photo series for the Sierra mixed conifer and Sierra true fir types (Maxwell and Ward 1979). Fire behavior estimates are based solely on measured fuel loadings in the 1/4- to 3-inch diameter range. All other inputs to a mathematical fire spread model (Rothermel 1972), including depth of fuel bed and 1-hour timelag (0- to 1/4-inch diameter) loading, are generated by assuming similarity of the fuel bed to a stylized fuel model. Packing and surface-to-volume ratios were derived by interpolation between models. Foliage and litter loadings are reflected in the 1-hour timelag fuel loading. No live or coarse (greater than 3-inch diameter) fuels are considered.

Two sets of fuel models are in widespread use for fire planning and hazard appraisal--Northern Forest Fire Laboratory (NFFL) and National Fire-Danger Rating (NFDR) models. The NFFL models (Albini 1976) are also used for forecasting behavior of wildfire. Generally, the slash fuel models reflect an average of typical fuel conditions in Douglas-fir and ponderosa pine slash. The NFDR models (Deeming et al. 1977) differ from the NFFL series mainly in that a greater proportion of 1-hour timelag fuels are present relative to 10- and 100-hour fuels (1/4 inch to 3 inches). Packing ratios are similar, but NFFL models have more nearly optimum packing. Because of these differences, predictions for spread and intensity of fire for fuels with properties of the NFDR slash models will be slightly greater at low windspeeds--and much greater at high windspeeds--than fuels with the physical properties of NFFL slash models.

A choice between using the NFFL or NFDR series of models to represent the fuel bed in a photo from Maxwell and Ward (1979) was based on the proportion of fine fuels present and on the believability of the output on fire behavior. Residues from second-growth timber and red slash, because of a greater amount of 1-hour fuel loading, are better represented by NFDR models. Old-growth or overwintered slash has characteristics similar to NFFL models.

Rothermel's (1972) fire spread model is the basis for estimates of fire behavior. The algorithm used to estimate flame lengths for photographs judged similar to NFDR fuel models is the same used in the NFDR system. The fire spread model, however, depends on a continuous and homogeneous fuel bed, and adjustments are needed if those conditions do not prevail. Several fuel beds depicted in the

Tables 1-30 provide a means to quantify relative differences in fire potential between fuel beds in a manner consistent with, but more precisely than, stylized fuel models. The user should not expect predicted values to be exact estimates of fire behavior on an actual fire on a specific unit. Deviations from one-half to two times the predicted values can be expected. Even values one-fourth to four times the actual value may occur. Deviations are also possible if the fuel inventory is inaccurate or if the character of the fuel bed is substantially different from the stylized fuel model.

Spread of fire is amplified by wind and slope. Effective wind (Albini 1976) is the windspeed that alone would produce the same amplification as the combined effects of wind and slope. The tables show effective wind at midflame height. Figure 1 can be used to determine effective midflame windspeed.

Fuel moisture content is calculated by combining the three fine fuel classes so that:

$$\begin{aligned} \text{Moisture content} = {} & 0.76 \times (\text{1-hour timelag moisture}) \\ & +0.18 \times (\text{10-hour timelag moisture}) \\ & +0.06 \times (\text{100-hour timelag moisture}). \end{aligned}$$

Fire perimeter, area, and resistance to control are also useful for fire planning. Formula and graphic aids (Fire Behavior Officer's Field Reference[1]) for determining perimeter and area are presented in appendix 1. Fuel resistance to control rating, slope, and flame length adjustment factors, and

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[1] National Interagency Fire Training Center, Marana, Arizona, 1978.

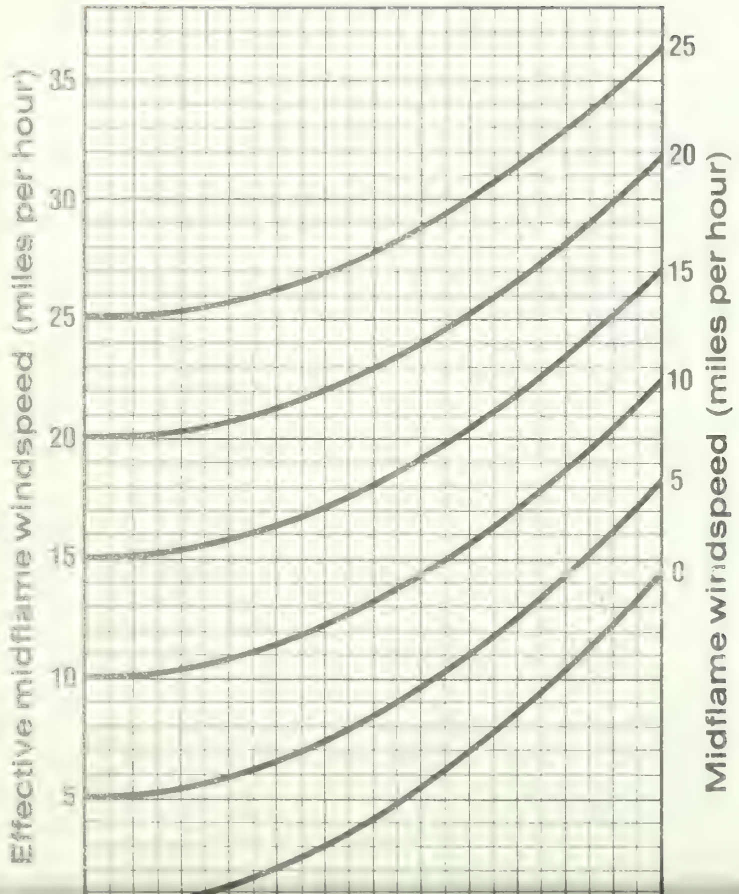

Figure 1.--Chart for determining effective windspeed from midflame windspeed and ground slope in direction of wind.

conversion of resistance to control rating values to chains per ... constructed by one person are presented in appendix 2.

For the approximate potential fire behavior and resistance of fuel to control for a particular area and given weather conditions, determine the following:

1. Which photo nearly matches, or which photos bracket, the area.
2. Rate of spread of fire and flame length (tables 1-30).
3. Perimeter and area of fire (from graphs and formulas in appendix 1).
4. Resistance of fuel to control (from tables in appendix 2).

For example, if the area was represented by photo 2-MC-4-RC in Maxwell and Ward (1979) and there was a 5-mi/h wind at midflame height, a fine fuel moisture of 4 percent, and the area was on a 20-percent slope, the following conditions would exist:

Effective midflame wind (miles per hour)--6
Rate of spread (chains per hour)--10
Flame length (feet)--6
Perimeter growth at 1 hour (chains)--29.3
Area at 1 hour (acres)--5.2
Resistance to suppression (chains/person-hour)--1.2

If the area was bracketed by two photos, interpolate by using the respective tables.

Literature Cited

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1976. Estimating wildfire behavior and effects. USDA For. Serv. Gen. Tech. Rep. INT-30, 92 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

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Mixed Conifer

Size Class 4

Regeneration Cut

Tables 1 through 3

(Corresponds to Photo Series 1-MC-4-RC to 3-MC-4-RC in Maxwell and Ward 1979)

TABLE 1--FIRE BEHAVIOR AND CONTROL INFORMATION FOR PHOTO 1-MC-4-RC

FUEL MOISTURE	RATE OF SPREAD: EFFECTIVE MIDFLAME WIND (MI/H)									FLAME LENGTH: EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

(FIRE BEHAVIOR INFORMATION SCALED FROM NFFL MODELS)

FUEL MOISTURE	RATE OF SPREAD									FLAME LENGTH								
	EFFECTIVE MIDFLAME WIND (MI/H)									EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	1	4	8	13	17	22	27	35	48	2	4	5	7	8	9	9	11	12
3	1	4	7	11	15	19	23	30	41	2	4	5	6	7	8	8	9	11
4	1	3	6	10	13	17	21	26	37	2	3	4	5	6	7	8	8	10
5	1	3	6	9	12	15	19	24	33	2	3	4	5	6	6	7	8	9
6	1	3	5	8	11	14	17	22	31	1	3	4	5	5	6	7	8	9
7	1	3	5	8	11	14	17	21	29	1	3	4	5	5	6	6	7	8
8	1	3	5	7	10	13	16	20	28	1	3	4	4	5	6	6	7	8
9	1	2	5	7	10	12	15	19	27	1	3	4	4	5	6	6	7	8
10	1	2	4	7	9	12	14	18	25	1	3	3	4	5	5	6	7	8
11	0	2	4	6	8	11	13	17	23	1	2	3	4	5	5	6	6	7
12	0	2	4	5	7	10	12	15	21	1	2	3	4	4	5	5	6	7
13	0	2	3	5	6	8	10	13	17	1	2	3	3	4	4	4	5	6
14	0	1	2	3	5	6	7	9	13	1	1	2	2	3	3	3	4	4
15	0	1	1	2	3	4	4	6	8	0	1	1	2	2	2	2	2	3
16	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1

TABLE 3--FIRE BEHAVIOR AND CONTROL INFORMATION FOR PHOTO 3-MC-4-RC
(FIRE BEHAVIOR INFORMATION SCALED FROM NFFL MODELS)

FUEL MOISTURE	RATE OF SPREAD									FLAME LENGTH								
	EFFECTIVE MIDFLAME WIND (MI/H)									EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	1	3	6	9	12	15	19	24	34	1	3	4	4	5	6	6	7	8
3	1	3	5	8	10	13	16	21	29	1	2	3	4	4	5	5	6	7
4	0	2	4	7	9	12	14	18	25	1	2	3	3	4	4	5	6	6
5	0	2	4	6	8	11	13	17	23	1	2	3	3	4	4	5	5	6
6	0	2	4	6	8	10	12	16	22	1	2	3	3	4	4	4	5	6
7	0	2	4	5	7	10	12	15	21	1	2	2	3	3	4	4	5	6
8	0	2	3	5	7	9	11	14	20	1	2	2	3	3	4	4	5	5
9	0	2	3	5	7	9	10	13	19	1	2	2	3	3	4	4	4	5
10	0	1	3	4	6	8	10	12	17	1	2	2	3	3	3	4	4	5
11	0	1	3	4	5	7	8	11	15	1	1	2	2	3	3	3	4	4
12	0	1	2	3	4	5	7	9	12	1	1	2	2	2	3	3	3	4
13	0	1	1	2	3	4	5	6	8	0	1	1	1	2	2	2	2	3
14	0	0	1	1	1	1	2	2	3	0	0	0	1	1	1	1	1	1

Mixed Conifer

Size Class 4

Partial Cut

Tables 4 Through 11

(Corresponds to Photo Series 1-MC-4-PC to 8-MC-4-PC in Maxwell and Ward 1979)

TABLE 4--FIRE BEHAVIOR AND CONTROL INFORMATION FOR PHOTO 1-MC-4-PC (RATE OF SPREAD ESTIMATES ARE ONE-HALF OF NFFL CONTINUOUS SLASH MODEL)

FUEL MOISTURE	RATE OF SPREAD									FLAME LENGTH								
	EFFECTIVE MIDFLAME WIND (MI/H)									EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	0	1	2	3	5	6	7	9	13	1	1	2	2	3	3	3	3	4
3	0	1	2	3	4	5	6	8	11	1	1	2	2	2	2	3	3	4
4	0	1	2	3	3	4	5	7	10	1	1	1	2	2	2	2	3	3
5	0	1	2	2	3	4	5	6	9	0	1	1	2	2	2	2	3	3
6	0	1	1	2	3	4	5	6	8	0	1	1	2	2	2	2	3	3
7	0	1	1	2	3	4	4	5	8	0	1	1	2	2	2	2	2	3
8	0	1	1	2	3	3	4	5	7	0	1	1	1	2	2	2	2	3
9	0	1	1	2	2	3	4	5	7	0	1	1	1	2	2	2	2	3
10	0	1	1	2	2	3	3	4	6	0	1	1	1	1	2	2	2	2
11	0	0	1	1	2	2	3	4	5	0	1	1	1	1	1	2	2	2
12	0	0	1	1	1	2	2	3	4	0	0	1	1	1	1	1	1	2
13	0	0	0	0	1	1	1	1	2	0	0	0	0	1	1	1	1	1

TABLE 5--FIRE BEHAVIOR AND CONTROL INFORMATION FOR PHOTO 2-MC-4-PC (RATE OF SPREAD ESTIMATES ARE ONE-HALF OF NFFL CONTINUOUS SLASH MODEL)

FUEL MOISTURE	RATE OF SPREAD									FLAME LENGTH								
	EFFECTIVE MIDFLAME WIND (MI/H)									EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	0	2	3	5	7	9	11	14	20	1	2	3	4	4	5	5	6	7
3	0	1	3	4	6	8	9	12	17	1	2	3	3	4	4	5	5	6
4	0	1	3	4	5	7	8	11	15	1	2	2	3	3	4	4	5	5
5	0	1	2	4	5	6	8	10	14	1	2	2	3	3	4	4	4	5
6	0	1	2	3	5	6	7	9	13	1	2	2	3	3	3	4	4	5
7	0	1	2	3	4	6	7	9	12	1	2	2	3	3	3	4	4	5
8	0	1	2	3	4	5	6	8	11	1	2	2	2	3	3	4	4	5
9	0	1	2	3	4	5	6	8	11	1	1	2	2	3	3	3	4	4
10	0	1	2	3	4	5	6	7	10	1	1	2	2	3	3	3	4	4
11	0	1	2	2	3	4	5	6	9	1	1	2	2	2	3	3	3	4
12	0	1	1	2	3	3	4	5	8	1	1	1	2	2	2	3	3	3
13	0	1	1	2	2	3	3	4	6	0	1	1	1	2	2	2	2	3
14	0	0	1	1	1	2	2	2	3	0	1	1	1	1	1	1	1	2
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

TABLE 6--FIRE BEHAVIOR AND CONTROL INFORMATION FOR PHOTO 3-MC-4-PC

FUEL MOISTURE	RATE OF SPREAD									FLAME LENGTH								
	EFFECTIVE MIDFLAME WIND (MI/H)									EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Mixed Conifer

Size Class 4

Partial Cut

Tables 4 Through 11

(Corresponds to Photo Series 1-MC-4-PC to 8-MC-4-PC in Maxwell and Ward 1979)

TABLE 8--FIRE BEHAVIOR AND CONTROL INFORMATION FOR PHOTO 5-MC-4-PC
(FIRE BEHAVIOR INFORMATION SCALED FROM NFFL MODELS)

FUEL MOISTURE	RATE OF SPREAD — EFFECTIVE MIDFLAME WIND (MI/H)									FLAME LENGTH — EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	1	4	3	13	17	22	27	34	47	2	4	5	6	7	8	9	10	12
3	1	4	7	11	15	19	23	29	40	2	3	5	6	7	7	8	9	11
4	1	3	6	10	13	17	20	26	36	2	3	4	5	6	7	7	8	10
5	1	3	6	9	12	15	18	24	32	2	3	4	5	6	6	7	8	9
6	1	3	5	8	11	14	17	22	30	1	3	4	5	5	6	7	7	9
7	1	3	5	8	10	13	16	21	29	1	3	4	4	5	6	6	7	8
8	1	2	5	7	10	13	15	20	27	1	3	4	4	5	6	6	7	8
9	1	2	5	7	9	12	15	19	26	1	3	3	4	5	5	6	7	8
10	1	2	4	7	9	11	14	18	24	1	2	3	4	5	5	6	6	7
11	0	2	4	6	8	10	13	16	22	1	2	3	4	4	5	5	6	7
12	0	2	3	5	7	9	11	14	20	1	2	3	3	4	4	5	5	6
13	0	1	3	4	6	8	9	12	17	1	2	2	3	3	4	4	5	5
14	0	1	2	3	4	6	7	9	12	1	1	2	2	3	3	3	4	4
15	0	1	1	2	3	3	4	5	7	0	1	1	1	2	2	2	2	2
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

(FIRE BEHAVIOUR INFORMATION SCALED FROM NFFL MODELS)

FUEL MOISTURE	RATE OF SPREAD — EFFECTIVE MIDFLAME WIND (MI/H) 0	2	4	6	8	10	12	14	16	FLAME LENGTH — EFFECTIVE MIDFLAME WIND (MI/H) 0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	1	5	9	14	19	24	30	38	52	2	5	6	7	9	10	10	12	14
3	1	4	8	12	16	21	26	33	45	2	4	5	7	8	8	9	10	12
4	1	4	7	11	15	18	23	29	40	2	4	5	6	7	8	8	9	11
5	1	3	6	10	13	17	20	26	36	2	3	5	6	6	7	8	9	10
6	1	3	6	9	12	16	19	24	34	2	3	4	5	6	7	7	8	10
7	1	3	6	8	12	15	18	23	32	2	3	4	5	6	7	7	8	9
8	1	3	5	8	11	14	17	22	30	2	3	4	5	6	6	7	8	9
9	1	3	5	8	10	13	16	21	29	2	3	4	5	6	6	7	8	9
10	1	2	5	7	10	13	15	20	27	1	3	4	5	5	6	7	7	8
11	1	2	4	7	9	12	14	19	26	1	3	4	4	5	6	6	7	8
12	0	2	4	6	8	11	13	17	23	1	2	3	4	5	5	6	6	7
13	0	2	4	5	7	9	11	15	20	1	2	3	4	4	5	5	6	7
14	0	1	3	4	6	8	9	12	16	1	2	2	3	3	4	4	5	6
15	0	1	2	3	4	5	6	8	11	1	1	2	2	3	3	3	3	4
16	0	0	1	1	2	2	3	4	5	0	1	1	1	1	1	2	2	2

TABLE 10--FIRE BEHAVIOR AND CONTROL INFORMATION FOR PHOTO 7-MC-4-PC
(FIRE BEHAVIOR INFORMATION SCALED FROM NFFL MODELS)

FUEL MOISTURE	RATE OF SPREAD — EFFECTIVE MIDFLAME WIND (MI/H)									FLAME LENGTH — EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	1	5	9	13	19	23	28	36	50	2	4	6	7	8	9	10	11	13
3	1	4	8	12	16	20	24	31	43	2	4	5	6	7	8	9	10	11
4	1	3	7	10	14	18	22	26	38	2	3	5	6	7	7	8	9	10
5	1	3	6	9	13	16	20	25	35	2	3	4	5	6	7	7	8	10
6	1	3	6	9	12	15	18	23	32	2	3	4	5	6	6	7	8	9
7	1	3	5	8	11	14	17	22	30	2	3	4	5	6	6	7	8	9
8	1	3	5	8	11	13	16	21	29	1	3	4	5	5	6	7	7	9
9	1	3	5	7	10	13	16	20	28	1	3	4	5	5	6	6	7	8
10	1	2	5	7	10	12	15	19	26	1	3	4	4	5	6	6	7	8
11	1	2	4	7	9	11	14	18	24	1	3	3	4	5	5	6	7	8
12	0	2	4	6	8	10	12	16	22	1	2	3	4	4	5	5	6	7
13	0	2	3	5	7	9	11	14	19	1	2	3	3	4	4	5	5	6
14	0	1	3	4	5	7	8	11	15	1	2	2	3	3	4	4	4	5
15	0	1	2	3	3	4	5	7	10	1	1	2	2	2	2	3	3	3
16	0	0	1	1	1	2	2	2	3	0	0	1	1	1	1	1	1	1

(FIRE BEHAVIOR INFORMATION SCALED FROM NFFL MODELS)

FUEL MOISTURE	RATE OF SPREAD									FLAME LENGTH								
	EFFECTIVE MIDFLAME WIND (MI/H)									EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	1	4	8	12	16	21	26	33	45	2	4	5	6	7	8	9	10	11
3	1	4	7	10	14	18	22	28	39	2	3	5	5	6	7	8	9	10
4	1	3	6	9	12	16	19	25	34	2	3	4	5	6	6	7	8	9
5	1	3	5	8	11	14	18	23	31	1	3	4	5	5	6	7	7	9
6	1	3	5	8	11	13	16	21	29	1	3	4	4	5	6	6	7	8
7	1	2	5	7	10	13	16	20	28	1	3	4	4	5	6	6	7	8
8	1	2	5	7	10	12	15	19	26	1	3	3	4	5	5	6	7	8
9	1	2	4	7	9	12	14	18	25	1	2	3	4	5	5	6	6	7
10	0	2	4	6	9	11	13	17	23	1	2	3	4	4	5	5	6	7
11	0	2	4	6	8	10	12	16	21	1	2	3	4	4	5	5	6	7
12	0	2	3	5	7	9	11	14	19	1	2	3	3	4	4	5	5	6
13	0	1	3	4	6	7	9	11	15	1	2	2	3	3	4	4	4	5
14	0	1	2	3	4	5	6	8	11	1	1	2	2	2	3	3	3	4
15	0	0	1	1	2	3	3	4	6	0	1	1	1	1	1	2	2	2

Mixed Conifer

Size Class 3

Partial Cut

Tables 12 Through 19

(Corresponds to Photo Series 1-MC-3-PC to 8-MC-3-PC in Maxwell and Ward 1979)

(FIRE BEHAVIOR INFORMATION SCALED FROM NFFL MODELS)

FUEL MOISTURE	RATE OF SPREAD: EFFECTIVE MIDFLAME WIND (MI/H)									FLAME LENGTH: EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	0	2	3	5	7	9	12	15	21	1	1	2	2	3	3	3	4	4
3	0	1	3	5	6	8	10	13	18	1	1	2	2	2	3	3	3	4
4	0	1	3	4	6	7	9	11	16	1	1	2	2	2	2	3	3	4
5	0	1	2	4	5	7	8	10	14	1	1	1	2	2	2	3	3	3
6	0	1	2	4	5	6	8	10	14	0	1	1	2	2	2	2	3	3
7	0	1	2	3	5	6	7	9	13	0	1	1	2	2	2	2	3	3
8	0	1	2	3	4	6	7	9	12	0	1	1	2	2	2	2	3	3
9	0	1	2	3	4	5	6	8	11	0	1	1	1	2	2	2	2	3
10	0	1	2	3	3	4	5	7	10	0	1	1	1	2	2	2	2	3
11	0	1	1	2	3	4	4	6	8	0	1	1	1	1	1	2	2	2
12	0	0	1	1	2	2	3	4	5	0	0	1	1	1	1	1	1	1
13	0	0	0	0	1	1	1	1	2	0	0	0	0	0	0	0	0	1

TABLE 13--FIRE BEHAVIOR AND CONTROL INFORMATION FOR PHOTO 2-MC-3-PC
(FIRE BEHAVIOR INFORMATION SCALED FROM NFDR MODELS)

FUEL MOISTURE	RATE OF SPREAD									FLAME LENGTH								
	EFFECTIVE MIDFLAME WIND (MI/H)									EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	1	5	10	15	21	28	34	45	64	2	4	6	8	9	10	11	13	15
3	1	4	8	13	19	24	30	40	57	2	4	6	7	8	9	10	12	14
4	1	4	7	12	17	22	27	36	51	2	4	5	6	7	8	9	11	12
5	1	3	7	11	15	20	24	32	46	2	3	5	6	7	8	9	10	11
6	1	3	6	10	14	18	22	29	42	2	3	4	5	6	7	8	9	10
7	1	3	6	9	13	17	21	27	39	2	3	4	5	6	7	7	8	10
8	1	3	5	8	12	16	19	25	36	1	3	4	5	5	6	7	8	9
9	1	2	5	8	11	15	18	24	34	1	3	3	4	5	6	6	7	8
10	1	2	5	8	11	14	17	23	33	1	2	3	4	5	5	6	7	8
11	1	2	5	7	10	13	17	22	31	1	2	3	4	4	5	5	6	7
12	1	2	4	7	10	13	16	21	30	1	2	3	4	4	5	5	6	7
13	1	2	4	7	10	12	16	20	29	1	2	3	3	4	4	5	5	6
14	0	2	4	7	9	12	15	20	28	1	2	2	3	4	4	4	5	6
15	0	2	4	6	9	11	14	19	27	1	2	2	3	3	4	4	5	6
16	0	2	4	6	8	11	14	18	25	1	2	2	3	3	3	4	4	5
17	0	2	4	6	8	10	13	17	24	1	1	2	2	3	3	3	4	5
18	0	2	3	5	7	9	12	16	22	1	1	2	2	2	3	3	4	4
19	0	1	3	5	7	9	11	14	20	1	1	2	2	2	2	3	3	4
20	0	1	3	4	6	8	10	12	18	0	1	1	2	2	2	2	3	3
21	0	1	2	4	5	6	8	11	15	0	1	1	1	2	2	2	2	3

(FIRE BEHAVIOR INFORMATION SCALED FROM NFFL MODELS)

FUEL MOISTURE	RATE OF SPREAD: EFFECTIVE MIDFLAME WIND (MI/H)									FLAME LENGTH: EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	1	3	5	8	11	14	17	22	30	1	2	3	4	4	5	5	6	7
3	0	2	4	7	9	12	14	19	26	1	2	3	3	4	4	5	5	6
4	0	2	4	6	8	10	13	16	23	1	2	2	3	3	4	4	5	6
5	0	2	4	5	7	10	12	15	21	1	2	2	3	3	4	4	5	5
6	0	2	3	5	7	9	11	14	20	1	2	2	3	3	4	4	4	5
7	0	2	3	5	7	9	10	13	19	1	2	2	3	3	3	4	4	5
8	0	2	3	5	6	8	10	13	18	1	2	2	3	3	3	4	4	5
9	0	1	3	4	6	8	9	12	16	1	1	2	2	3	3	3	4	4
10	0	1	3	4	5	7	8	11	15	1	1	2	2	3	3	3	4	4
11	0	1	2	3	5	6	7	9	13	1	1	2	2	2	3	3	3	4
12	0	1	2	3	4	4	5	7	10	0	1	1	2	2	2	2	2	3
13	0	1	1	2	2	3	3	4	6	0	1	1	1	1	1	1	2	2
14	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0

TABLE 15--FIRE BEHAVIOR AND CONTROL INFORMATION FOR PHOTO 4-MC-3-PC
(FIRE BEHAVIOR INFORMATION SCALED FROM NFFL MODELS)

FUEL MOISTURE	RATE OF SPREAD — EFFECTIVE MIDFLAME WIND (MI/H)									FLAME LENGTH — EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	1	3	6	10	13	17	20	26	36	1	3	4	5	5	6	7	7	9
3	1	3	5	8	11	14	17	22	31	1	3	3	4	5	5	6	7	8
4	1	2	5	7	10	13	15	20	27	1	2	3	4	4	5	5	6	7
5	0	2	4	7	9	12	14	18	25	1	2	3	4	4	5	5	6	7
6	0	2	4	6	8	11	13	17	23	1	2	3	3	4	4	5	5	6
7	0	2	4	6	8	10	13	16	22	1	2	3	3	4	4	5	5	6
8	0	2	4	6	8	10	12	15	21	1	2	3	3	4	4	5	5	6
9	0	2	3	5	7	9	11	14	20	1	2	3	3	4	4	4	5	6
10	0	2	3	5	7	8	10	13	18	1	2	2	3	3	4	4	5	5
11	0	1	3	4	6	7	9	12	16	1	2	2	3	3	3	4	4	5
12	0	1	2	4	5	6	8	10	13	1	1	2	2	3	3	3	4	4
13	0	1	2	3	3	4	5	7	10	0	1	1	2	2	2	2	3	3
14	0	0	1	1	2	2	3	3	5	0	1	1	1	1	1	1	1	2

FUEL MOISTURE	RATE OF SPREAD: EFFECTIVE MIDFLAME WIND (MI/H)									FLAME LENGTH: EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	1	5	10	15	22	28	35	46	66	2	4	6	7	9	10	11	12	14
3	1	4	9	14	19	25	31	41	58	2	4	5	7	8	9	10	11	13
4	1	4	8	12	17	22	28	37	52	2	4	5	6	7	8	9	10	12
5	1	3	7	11	15	20	25	33	47	2	3	5	6	7	7	8	9	11
6	1	3	6	10	14	18	23	30	43	2	3	4	5	6	7	8	9	10
7	1	3	6	9	13	17	21	28	40	1	3	4	5	6	6	7	8	9
8	1	3	6	9	12	16	20	26	37	1	3	4	4	5	6	7	7	9
9	1	3	5	8	12	15	19	25	35	1	2	3	4	5	5	6	7	8
10	1	2	5	8	11	14	18	24	34	1	2	3	4	5	5	6	6	8
11	1	2	5	8	11	14	17	23	32	1	2	3	4	4	5	5	6	7
12	1	2	5	7	10	13	17	22	31	1	2	3	3	4	4	5	6	7
13	1	2	4	7	10	13	16	21	30	1	2	3	3	4	4	5	5	6
14	1	2	4	7	9	12	15	20	29	1	2	2	3	3	4	4	5	6
15	0	2	4	6	9	12	15	19	27	1	2	2	3	3	4	4	5	5
16	0	2	4	6	9	11	14	18	26	1	1	2	3	3	3	4	4	5
17	0	2	4	6	8	11	13	17	25	1	1	2	2	3	3	3	4	4
18	0	2	3	5	7	10	12	16	23	1	1	2	2	2	3	3	3	4
19	0	1	3	5	7	9	11	15	21	1	1	1	2	2	2	3	3	4
20	0	1	3	4	6	8	10	13	18	0	1	1	2	2	2	2	3	3
21	0	1	2	4	5	7	8	11	15	0	1	1	1	2	2	2	2	3
22	0	1	2	3	4	5	7	9	12	0	1	1	1	1	1	1	2	2
23	0	1	1	2	3	4	5	6	9	0	0	1	1	1	1	1	1	1
24	0	0	1	1	1	2	2	3	5	0	0	0	0	0	1	1	1	1

TABLE 17--FIRE BEHAVIOR AND CONTROL INFORMATION FOR PHOTO 6-MC-3-PC
(FIRE BEHAVIOR INFORMATION SCALED FROM NFFL MODELS)

FUEL MOISTURE	RATE OF SPREAD: EFFECTIVE MIDFLAME WIND (MI/H)									FLAME LENGTH: EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	0	2	4	7	9	12	15	19	26	1	2	3	3	4	4	4	5	6
3	0	2	4	6	8	10	12	16	22	1	2	2	3	3	4	4	4	5
4	0	2	3	5	7	9	11	14	20	1	2	2	3	3	3	4	4	5
5	0	2	3	5	6	8	10	13	18	1	1	2	2	3	3	3	4	4
6	0	1	3	4	6	8	10	12	17	1	1	2	2	3	3	3	4	4
7	0	1	3	4	5	7	9	12	16	1	1	2	2	3	3	3	4	4
8	0	1	3	4	5	7	9	11	15	1	1	2	2	2	3	3	3	4
9	0	1	2	4	5	6	8	10	14	1	1	2	2	2	3	3	3	4
10	0	1	2	3	5	6	7	9	13	1	1	2	2	2	2	3	3	3
11	0	1	2	3	4	5	6	8	11	0	1	1	2	2	2	2	3	3
12	0	1	1	2	3	4	4	6	8	0	1	1	1	1	2	2	2	2
13	0	0	1	1	1	2	2	3	4	0	0	1	1	1	1	1	1	1

(FIRE BEHAVIOR INFORMATION SCALED FROM NFFL MODELS)

FUEL MOISTURE	RATE OF SPREAD — EFFECTIVE MIDFLAME WIND (MI/H)									FLAME LENGTH — EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	1	4	9	13	18	23	28	35	49	2	4	6	7	8	9	10	11	13
3	1	4	7	11	15	20	24	31	42	2	4	5	6	7	8	9	10	11
4	1	3	7	10	14	17	21	27	37	2	3	5	6	6	7	8	9	10
5	1	3	6	9	12	16	19	25	34	2	3	4	5	6	7	7	8	9
6	1	3	6	8	11	15	18	23	31	2	3	4	5	5	6	7	8	9
7	1	3	5	8	11	14	17	22	30	1	3	4	5	5	6	7	7	9
8	1	3	5	8	10	13	16	21	28	1	3	4	5	5	6	6	7	8
9	1	2	5	7	10	13	15	20	27	1	3	4	4	5	6	6	7	8
10	1	2	4	7	9	12	14	19	26	1	3	4	4	5	5	6	7	8
11	0	2	4	6	9	11	13	17	24	1	2	3	4	5	5	6	6	7
12	0	2	4	6	8	10	12	15	21	1	2	3	4	4	5	5	6	7
13	0	2	3	5	7	8	10	13	18	1	2	3	3	4	4	5	5	6
14	0	1	2	4	5	6	8	10	14	1	2	2	3	3	3	4	4	5
15	0	1	2	2	3	4	5	6	9	1	1	1	2	2	2	2	3	3
16	0	0	0	1	1	1	1	2	2	0	0	0	0	1	1	1	1	1

TABLE 19--FIRE BEHAVIOR AND CONTROL INFORMATION FOR PHOTO 3-MC-3-PC

FUEL MOISTURE	RATE OF SPREAD: EFFECTIVE MIDFLAME WIND (MI/H)									FLAME LENGTH: EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

True Fir

Size Class 4

Regeneration Cut

Tables 20 Through 25

(Corresponds to Photo Series 1-TF-4-RC to 6-TF-4-RC in Maxwell and Ward 1979)

TABLE 20--FIRE BEHAVIOR AND CONTROL INFORMATION FOR PHOTO 1-TF-4-PC

FUEL MOISTURE	RATE OF SPREAD									FLAME LENGTH								
	EFFECTIVE MIDFLAME WIND (MI/H)									EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

FUEL MOISTURE	RATE OF SPREAD: EFFECTIVE MIDFLAME WIND (MI/H)									FLAME LENGTH: EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

TABLE 22--FIRE BEHAVIOR AND CONTROL INFORMATION FOR PHOTO 3-TF-4-RC (RATE OF SPREAD ESTIMATES ARE ONE-QUARTER OF NFFL CONTINUOUS SLASH MODEL)

FUEL MOISTURE	RATE OF SPREAD									FLAME LENGTH								
	EFFECTIVE MIDFLAME WIND (MI/H)									EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	0	1	2	3	4	5	6	7	10	1	2	2	3	3	4	4	4	5
3	0	1	2	2	3	4	5	6	9	1	1	2	2	3	3	3	4	5
4	0	1	1	2	3	4	4	6	8	1	1	2	2	3	3	3	4	4
5	0	1	1	2	3	3	4	5	7	1	1	2	2	2	3	3	3	4
6	0	1	1	2	2	3	4	5	7	1	1	2	2	2	3	3	3	4
7	0	1	1	2	2	3	4	5	6	1	1	2	2	2	2	3	3	4
8	0	1	1	2	2	3	3	4	6	1	1	2	2	2	2	3	3	3
9	0	1	1	2	2	3	3	4	6	1	1	1	2	2	2	3	3	3
10	0	0	1	1	2	2	3	4	5	1	1	1	2	2	2	2	3	3
11	0	0	1	1	2	2	3	3	5	0	1	1	2	2	2	2	3	3
12	0	0	1	1	1	2	2	3	4	0	1	1	1	2	2	2	2	3
13	0	0	1	1	1	1	2	2	3	0	1	1	1	1	1	2	2	2
14	0	0	0	1	1	1	1	1	2	0	0	1	1	1	1	1	1	1
15	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0

(RATE OF SPREAD ESTIMATES ARE ONE-HALF OF NFFL CONTINUOUS SLASH MODEL)

FUEL MOISTURE	RATE OF SPREAD									FLAME LENGTH								
	EFFECTIVE MIDFLAME WIND (MI/H)									EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	0	2	3	5	7	9	11	14	20	1	2	3	4	4	5	5	6	7
3	0	2	3	5	6	8	10	12	17	1	2	3	3	4	4	5	5	6
4	0	1	3	4	5	7	9	11	15	1	2	3	3	4	4	4	5	6
5	0	1	2	4	5	6	8	10	14	1	2	2	3	3	4	4	5	5
6	0	1	2	3	5	6	7	9	13	1	2	2	3	3	4	4	4	5
7	0	1	2	3	4	6	7	9	12	1	2	2	3	3	3	4	4	5
8	0	1	2	3	4	5	7	8	12	1	2	2	3	3	3	4	4	5
9	0	1	2	3	4	5	6	8	11	1	1	2	2	3	3	3	4	5
10	0	1	2	3	4	5	6	7	10	1	1	2	2	3	3	3	4	4
11	0	1	2	2	3	4	5	7	9	1	1	2	2	2	3	3	3	4
12	0	1	1	2	3	4	4	6	8	1	1	2	2	2	2	3	3	3
13	0	1	1	2	2	3	3	4	6	0	1	1	1	2	2	2	2	3
14	0	0	1	1	1	2	2	3	4	0	1	1	1	1	1	1	2	2
15	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0

TABLE 24--FIRE BEHAVIOR AND CONTROL INFORMATION FOR PHOTO 5-TF-4-RC
(FIRE BEHAVIOR INFORMATION SCALED FROM NFFL MODELS)

FUEL MOISTURE	RATE OF SPREAD									FLAME LENGTH								
	EFFECTIVE MIDFLAME WIND (MI/H)									EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	0	2	5	7	10	12	15	19	27	1	2	3	3	4	4	5	5	6
3	0	2	4	6	8	11	13	17	23	1	2	2	3	3	4	4	5	5
4	0	2	3	5	7	9	11	15	20	1	2	2	3	3	3	4	4	5
5	0	2	3	5	7	9	10	13	19	1	1	2	2	3	3	4	4	5
6	0	2	3	5	6	8	10	13	18	1	1	2	2	3	3	3	4	4
7	0	1	3	4	6	8	9	12	17	1	1	2	2	3	3	3	4	4
8	0	1	3	4	6	7	9	11	16	1	1	2	2	3	3	3	4	4
9	0	1	3	4	5	7	8	11	15	1	1	2	2	2	3	3	3	4
10	0	1	2	3	5	6	7	9	13	1	1	2	2	2	2	3	3	4
11	0	1	2	3	4	5	6	8	11	0	1	1	2	2	2	2	3	3
12	0	1	1	2	3	4	5	6	8	0	1	1	1	1	2	2	2	2
13	0	0	1	1	2	2	2	3	4	0	0	1	1	1	1	1	1	1

(FIRE BEHAVIOR INFORMATION SCALED FROM NFFL MODELS)

FUEL MOISTURE	RATE OF SPREAD: EFFECTIVE MIDFLAME WIND (MI/H)									FLAME LENGTH: EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	1	4	8	12	16	21	25	33	45	2	4	5	6	7	8	9	10	11
3	1	3	7	10	14	18	22	28	39	2	3	4	5	6	7	8	9	10
4	1	3	6	9	12	16	19	25	34	2	3	4	5	6	6	7	8	9
5	1	3	5	8	11	14	18	23	31	1	3	4	5	5	6	7	7	8
6	1	3	5	8	11	13	16	21	29	1	3	4	4	5	6	6	7	8
7	1	2	5	7	10	13	16	20	27	1	3	4	4	5	5	6	7	8
8	1	2	5	7	9	12	15	19	26	1	3	3	4	5	5	6	7	8
9	1	2	4	7	9	12	14	18	25	1	2	3	4	5	5	6	6	7
10	0	2	4	6	8	11	13	17	23	1	2	3	4	4	5	5	6	7
11	0	2	4	5	8	10	12	15	21	1	2	3	4	4	5	5	6	7
12	0	2	3	5	7	9	11	14	19	1	2	3	3	4	4	5	5	6
13	0	1	3	4	6	7	9	11	15	1	2	2	3	3	3	4	4	5
14	0	1	2	3	4	5	6	8	11	1	1	2	2	2	3	3	3	4
15	0	0	1	1	2	2	3	4	5	0	1	1	1	1	1	1	2	2

True Fir

Size Class 4

Partial Cut

Tables 26 Through 30

(Corresponds to Photo Series 1-TF-4-PC to 5-TF-4-PC in Maxwell and Ward 1979)

TABLE 26--FIRE BEHAVIOR AND CONTROL INFORMATION FOR PHOTO 1-TF-4-PC
(RATE OF SPREAD ESTIMATES ARE ONE-HALF OF NFFL CONTINUOUS
SLASH MODEL)

FUEL MOISTURE	RATE OF SPREAD — EFFECTIVE MIDFLAME WIND (MI/H)									FLAME LENGTH — EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	0	1	3	4	5	7	8	11	15	1	2	2	3	3	3	4	4	5
3	0	1	2	3	5	6	7	9	13	1	1	2	2	3	3	3	4	4
4	0	1	2	3	4	5	6	8	11	1	1	2	2	2	3	3	3	4
5	0	1	2	3	4	5	6	7	10	1	1	2	2	2	3	3	3	4
6	0	1	2	3	3	4	5	7	10	1	1	2	2	2	2	3	3	4
7	0	1	2	2	3	4	5	7	9	1	1	2	2	2	2	3	3	3
8	0	1	1	2	3	4	5	6	9	1	1	1	2	2	2	3	3	3
9	0	1	1	2	3	4	5	6	8	0	1	1	2	2	2	2	3	3
10	0	1	1	2	3	3	4	5	7	0	1	1	2	2	2	2	2	3
11	0	1	1	2	2	3	4	5	6	0	1	1	1	2	2	2	2	3
12	0	0	1	1	2	2	3	3	5	0	1	1	1	1	1	2	2	2
13	0	0	0	1	1	1	2	2	3	0	0	1	1	1	1	1	1	1
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

TABLE 27--FIRE BEHAVIOR AND CONTROL INFORMATION FOR PHOTO 2-TF-4-PC
(FIRE BEHAVIOR INFORMATION SCALED FROM NFFL MODELS)

FUEL MOISTURE	RATE OF SPREAD									FLAME LENGTH								
	EFFECTIVE MIDFLAME WIND (MI/H)									EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	0	2	4	7	9	12	14	16	26	1	2	3	3	4	4	4	5	6
3	0	2	4	6	8	10	12	16	22	1	2	2	3	3	4	4	4	5
4	0	2	3	5	7	9	11	14	19	1	1	2	2	3	3	4	4	5
5	0	2	3	5	6	8	10	13	18	1	1	2	2	3	3	3	4	4
6	0	1	3	4	6	8	9	12	17	1	1	2	2	3	3	3	4	4
7	0	1	3	4	6	7	9	11	16	1	1	2	2	3	3	3	3	4
8	0	1	3	4	5	7	8	11	15	1	1	2	2	2	3	3	3	4
9	0	1	2	4	5	6	8	10	14	1	1	2	2	2	3	3	3	4
10	0	1	2	3	4	6	7	9	12	1	1	1	2	2	2	3	3	3
11	0	1	2	3	4	5	6	7	10	0	1	1	2	2	2	2	2	3
12	0	1	1	2	3	3	4	5	7	0	1	1	1	1	2	2	2	2
13	0	0	1	1	1	2	2	3	4	0	0	1	1	1	1	1	1	1

(FIRE BEHAVIOUR INFORMATION SCALED FROM NFFL MODELS)

FUEL MOISTURE	RATE OF SPREAD — EFFECTIVE MIDFLAME WIND (MI/H)									FLAME LENGTH — EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	1	3	7	10	14	17	21	27	38	2	3	4	5	6	6	7	8	9
3	1	3	6	9	12	15	18	23	32	1	3	4	4	5	6	6	7	8
4	1	3	5	8	10	13	16	21	29	1	2	3	4	5	5	6	6	7
5	1	2	5	7	9	12	15	19	26	1	2	3	4	4	5	5	6	7
6	0	2	4	6	9	11	14	18	24	1	2	3	4	4	5	5	6	7
7	0	2	4	6	8	11	13	17	23	1	2	3	3	4	4	5	5	6
8	0	2	4	6	8	10	12	16	22	1	2	3	3	4	4	5	5	6
9	0	2	4	6	8	10	12	15	21	1	2	3	3	4	4	5	5	6
10	0	2	3	5	7	9	11	14	19	1	2	3	3	4	4	4	5	6
11	0	2	3	5	6	8	10	12	17	1	2	2	3	3	4	4	4	5
12	0	1	2	4	5	7	8	10	14	1	1	2	2	3	3	3	4	4
13	0	1	2	3	4	5	6	8	11	1	1	1	2	2	2	3	3	3
14	0	1	1	2	2	3	3	4	6	0	1	1	1	1	1	1	2	2

TABLE 29--FIRE BEHAVIOR AND CONTROL INFORMATION FOR PHOTO 4-TF-4-PC
(FIRE BEHAVIOR INFORMATION SCALED FROM NFFL MODELS)

FUEL MOISTURE	RATE OF SPREAD									FLAME LENGTH								
	EFFECTIVE MIDFLAME WIND (MI/H)									EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	1	4	8	12	16	21	25	32	45	2	4	5	6	7	8	9	10	11
3	1	3	7	10	14	18	22	28	38	2	3	4	5	5	7	8	9	10
4	1	3	6	9	12	16	19	25	34	2	3	4	5	6	6	7	8	9
5	1	3	5	[illegible]	11	14	18	22	31	1	3	4	5	5	6	7	7	8
6	1	3	5	[illegible]	10	13	16	21	29	1	3	4	4	5	6	6	7	8
7	1	2	5	7	10	13	15	20	27	1	3	3	4	5	5	6	7	8
8	1	2	5	7	9	12	15	19	26	1	2	3	4	5	5	6	7	8
9	1	2	4	7	9	11	14	18	25	1	2	3	4	5	5	6	6	7
10	0	2	4	5	8	11	13	17	23	1	2	3	4	4	5	5	6	7
11	0	2	4	6	8	10	12	15	21	1	2	3	4	4	5	5	6	7
12	0	2	3	5	7	9	11	13	19	1	2	3	3	4	4	5	5	6
13	0	1	3	4	5	7	9	11	15	1	2	2	3	3	3	4	4	5
14	0	1	2	3	4	5	6	8	11	1	1	2	2	2	3	3	3	4
15	0	0	1	1	2	2	3	4	5	0	1	1	1	1	1	1	2	2

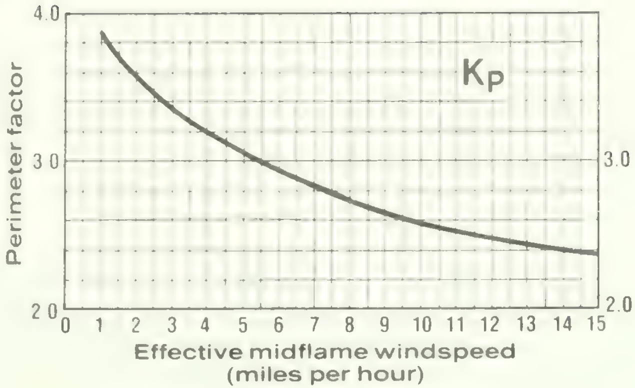
(FIRE BEHAVIOR INFORMATION SCALED FROM NFFL MODELS)

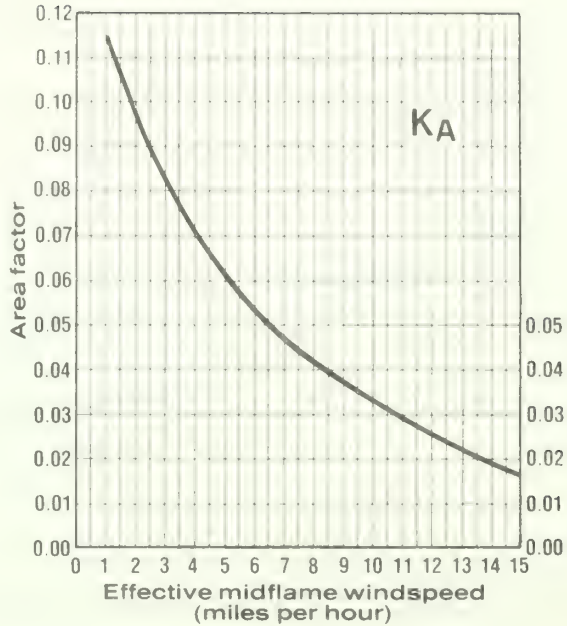
FUEL MOISTURE	RATE OF SPREAD: EFFECTIVE MIDFLAME WIND (MI/H)									FLAME LENGTH: EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	1	4	7	10	14	18	22	29	39	2	3	4	5	6	7	7	8	10
3	1	3	6	9	12	16	19	24	34	1	3	4	5	5	6	7	7	9
4	1	3	5	8	11	14	17	22	30	1	3	3	4	5	5	6	7	8
5	1	2	5	7	10	13	15	20	27	1	2	3	4	5	5	6	6	7
6	1	2	4	7	9	12	14	18	26	1	2	3	4	4	5	5	6	7
7	0	2	4	6	9	11	14	18	24	1	2	3	4	4	5	5	6	7
8	0	2	4	6	8	11	13	17	23	1	2	3	4	4	5	5	6	7
9	0	2	4	6	8	10	12	16	22	1	2	3	3	4	4	5	5	6
10	0	2	4	5	7	9	11	15	20	1	2	3	3	4	4	5	5	6
11	0	2	3	5	7	8	10	13	18	1	2	2	3	3	4	4	5	5
12	0	1	3	4	6	7	9	11	15	1	2	2	3	3	3	4	4	5
13	0	1	2	3	4	5	7	8	12	1	1	2	2	2	3	3	3	4
14	0	1	1	2	3	3	4	5	7	0	1	1	1	1	2	2	2	2
15	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0

Appendix 1

Fire Perimeter and Area Calculation Graphs and Formulas

(Adapted from Fire Behavior Officer's Field Reference, National Interagency Fire Training Center, Marana, Arizona)





P = Perimeter (chains)

$$P = K_pD$$
$$= K_p(RxT)$$

A = Area (acres)

$$A = K_AD^2$$
$$= K_A(RxT)^2$$

WHERE:

K_p = Perimeter factor
R = Rate of spread (chains per hour)
T = Time (hour); 1-hour maximum
K_A = Area factor
D = R x T; spread distance (chains)

Appendix 2

Resistance to control ratings, flame length adjustment factor, slope adjustment factor, and conversion of resistance to control rating values to chains per hour of line constructed by one person

The resistance to control rating (table 31) times flame length adjustment factor (table 32) times slope adjustment factor (table 33) equals the adjusted rating. Use table 34 to convert adjusted rating to actual resistance to control.

Table 31--Fuel resistance to control ratings by photo number[1]

PHOTO NUMBER	RATING	PHOTO NUMBER	RATING
1-MC-4-RC	4	1-TF-4-RC	1
2-MC-4-RC	11	2-TF-4-RC	2
3-MC-4-RC	30	3-TF-4-RC	9
		4-TF-4-RC	11
1-MC-4-PC	2	5-TF-4-RC	6
2-MC-4-PC	12	6-TF-4-RC	17
3-MC-4-PC	5		
4-MC-4-PC	10	1-TF-4-PC	4
5-MC-4-PC	13	2-TF-4-PC	7
6-MC-4-PC	17	3-TF-4-PC	8
7-MC-4-PC	20	4-TF-4-PC	17
8-MC-4-PC	17	5-TF-4-PC	27
1-MC-3-PC	2		
2-MC-3-PC	6		
3-MC-3-PC	5		
4-MC-3-PC	6		
5-MC-3-PC	7		
6-MC-3-PC	9		
7-MC-3-PC	13		
8-MC-3-PC	8		

[1]Ratings derived from matrix by Wayne G. Maxwell (on file at Pacific Northwest Forest and Range Experiment Station, Portland, Oregon).

Table 32--Flame length adjustment factor

Flame length (feet)	0-4	5-8	9-12	13+
Adjustment factor	1	1.5	2.0	3.0

Table 33--Slope adjustment factor

Slope (percent)	0-30	31-60	61-75	75+
Adjustment factor	1	1.2	1.5	1.9

Table 34--Conversion of rating values to chains per hour of line constructed by 1 person

Adjusted rating values	Chains per hour	Adjusted rating values	Chains per hour
1	12.00	13	0.92
2	6.00	14	.86
3	4.00	15	.80
4	3.00	16	.75
5	2.40	17	.71
6	2.00	18	.67
7	1.70	19	.63
8	1.50	20	.60
9	1.30	25	.48
10	1.20	30	.40
11	1.10	35	.34
12	1.00	40	.30

General Technical

The **Forest Service** of the U.S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.

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PREDICTIONS OF FIRE BEHAVIOR AND RESISTANCE TO CONTROL

FOR USE WITH PHOTO SERIES FOR THE PONDEROSA PINE TYPE, PONDEROSA PINE AND ASSOCIATED SPECIES TYPE, AND LODGEPOLE PINE TYPE

FRANKLIN R. WARD
DAVID V. SANDBERG

A COOPERATIVE
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This publication presents tables on the behavior of fire and the resistance of fuels to control. The information is to be used with the publication, "Photo Series for Quantifying Forest Residues in the Ponderosa Pine Type, Ponderosa Pine and Associated Species Type, Lodgepole Pine Type" (USDA For. Serv. Gen. Tech. Rep. PNW-52, 1976, by Wayne G. Maxwell and Franklin R. Ward).

KEYWORDS: Fire behavior (forest), fire management, fire spread.

Metric Conversion

To change	to	multiply by:
Miles per hour	kilometers per hour	1.6093
Chains	meters	20.12
Feet	meters	0.3048
Acres	hectares	0.4047

Species List

Douglas-fir	*Pseudotsuga menziesii* (Mirb.) Franco
ponderosa pine	*Pinus ponderosa* Dougl. ex Laws.
lodgepole pine	*Pinus contorta* Dougl. ex Loud.

windthrow, ice damage, and wildfire--often leave undesirable amounts of forest residues. The forest manager must set limits on the amount of residues and fire hazard that are consistent with resource management objectives.

Photo series have been published as an inventory tool to assess fuel loadings by size class in several forest types. The photos are used to translate visual images to quantities (tons per acre) so the manager can describe the residue that should be retained to meet environmental concerns and goals of a particular specialty. The photos also provide a starting point for assessing fire hazard.

This publication presents tables for predicting rate of fire spread, flame length, and resistance of fuel to control for each residue condition depicted by the photo series for the ponderosa pine, ponderosa pine and associated species, and lodgepole pine types (Maxwell and Ward 1976). Fire behavior estimates are based solely on measured fuel loadings in the 1/4- to 3-inch diameter range. All other inputs to a mathematical fire spread model (Rothermel 1972), including depth of fuel bed and 1-hour timelag (0- to 1/4-inch diameter) loading, are generated by assuming similarity of the fuel bed to a stylized fuel model. Packing and surface-to-volume ratios were derived by interpolation between models. Foliage and litter loadings are reflected in the 1-hour timelag fuel loading. No live or coarse (greater than 3-inch diameter) fuels are considered.

Two sets of fuel models are in widespread use for fire planning and hazard appraisal--Northern Forest Fire Laboratory (NFFL) and National Fire-Danger Rating (NFDR) models. The NFFL models (Albini 1976) are also used for forecasting behavior of wildfire. Generally, the slash fuel models reflect an average of typical fuel conditions in Douglas-fir and ponderosa pine slash. The NFDR models (Deeming et al. 1977) differ from the NFFL series mainly in that a greater proportion of 1-hour timelag fuels are present relative to 10- and 100-hour fuels (1/4 inch to 3 inches). Packing ratios are similar, but NFFL models have more nearly optimum packing. Because of these differences, predictions for spread and intensity of fire for fuels with properties of the NFDR slash models will be slightly greater at low windspeeds--and much greater at high windspeeds--than fuels with the physical properties of NFFL slash models.

A choice between using the NFFL or NFDR series of models to represent the fuel bed in a photo from Maxwell and Ward (1976) was based on the proportion of fine fuels present and on the believability of the output on fire behavior. Residues from second-growth timber and red slash, because of a greater amount of 1-hour fuel loading, are better represented by NFDR models. Old-growth or overwintered slash has characteristics similar to NFFL models.

Rothermel's (1972) fire spread model is the basis for estimates of fire behavior. The algorithm used to estimate flame lengths for photographs judged similar to NFDR fuel models is the same used in the NFDR system. The fire spread model, however, depends on a continuous and homogeneous fuel bed, and adjustments are needed if those conditions do not prevail. Several fuel beds depicted in the photo series by Maxwell and Ward (1976) were treated by fire or mechanical

fuel models. The user should not expect predicted values to be exact estimates of fire behavior on an actual fire on a specific unit. Deviations from one-half to two times the predicted values can be expected. Even values one-fourth to four times the actual value may occur. Deviations are also possible if the fuel inventory is inaccurate or if the character of the fuel bed is substantially different from the stylized fuel model.

Spread of fire is amplified by wind and slope. Effective wind (Albini 1976) is the windspeed that alone would produce the same amplification as the combined effects of wind and slope. The tables show effective wind at midflame height. Figure 1 can be used to determine effective midflame windspeed.

Fuel moisture content is calculated by combining the three fine fuel classes so that:

$$\begin{aligned}\text{Moisture content} = {} & 0.76 \times (\text{1-hour timelag moisture}) \\ & +0.18 \times (\text{10-hour timelag moisture}) \\ & +0.06 \times (\text{100-hour timelag moisture}).\end{aligned}$$

Fire perimeter, area, and resistance to control are also useful for fire planning. Formula and graphic aids (Fire Behavior Officer's Field Reference[1]) for determining perimeter and area are presented in appendix 1. Fuel resistance to control rating, slope, and flame length adjustment factors, and

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[1] National Interagency Fire Training Center, Marana, Arizona, 1978.

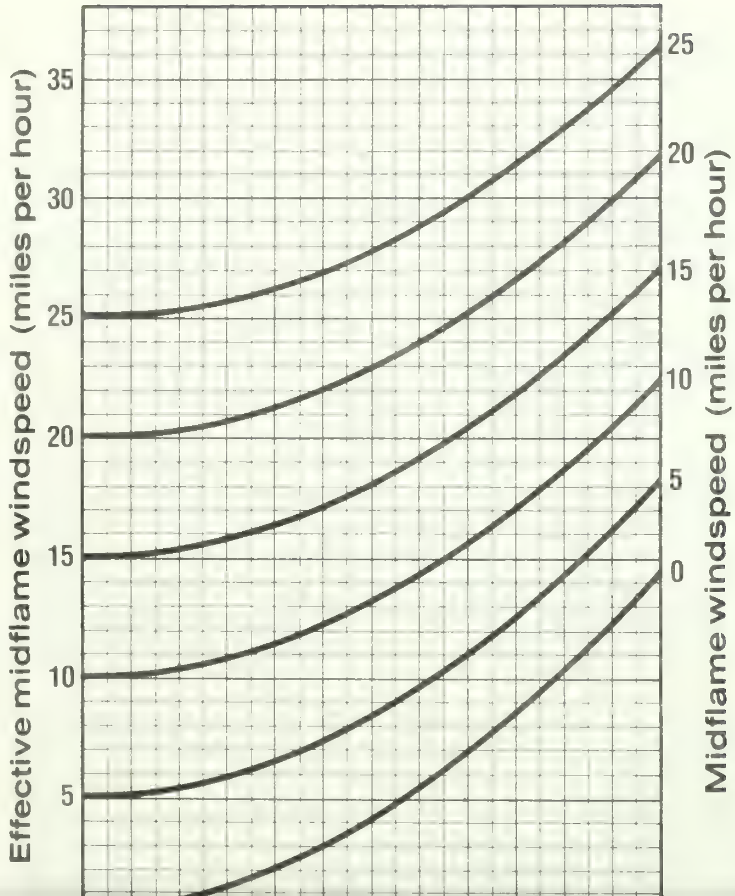

Figure 1.--Chart for determining effective windspeed from midflame windspeed and ground slope in direction of wind.

constructed by one person are presented in appendix 2.

For the approximate potential fire behavior and resistance of fuel to control for a particular area and given weather conditions, determine the following:

1. Which photo nearly matches, or which photos bracket, the area.
2. Rate of spread of fire and flame length (tables 1-27).
3. Perimeter and area of fire (from graphs and formulas in appendix 1).
4. Resistance of fuel to control (from tables in appendix 2).

For example, if the area was represented by photo 1-PP-4-CC in Maxwell and Ward (1976) and there was a 5-mi/h wind at midflame height, a fine fuel moisture of 4 percent, and the area was on a 20-percent slope, the following conditions would exist:

Effective midflame wind (miles per hour)--6
Rate of spread (chains per hour)--16
Flame length (feet)--9
Perimeter growth at 1 hour (chains)--46.9
Area at 1 hour (acres)--13.3
Resistance to suppression (chains/person-hour)--3.0

If the area was bracketed by two photos, interpolate by using the respective tables.

Literature Cited

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Ponderosa Pine

Size Class 4

Clearcut

Tables 1 Through 2

(Corresponds to Photo Series 1-PP-4-CC to 2-PP-4-CC in Maxwell and Ward 1976)

TABLE 1--FIRE BEHAVIOR AND CONTROL INFORMATION FOR PHOTO 1-PP-4-CC
(FIRE BEHAVIOR INFORMATION SCALED FROM NFDR MODELS)

FUEL MOISTURE	RATE OF SPREAD									FLAME LENGTH								
	EFFECTIVE MIDFLAME WIND (MI/H)									EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	2	6	13	20	28	37	46	61	86	3	6	8	10	12	14	15	17	20
3	1	6	11	18	25	33	41	54	76	3	5	8	9	11	12	14	15	18
4	1	5	10	16	22	29	36	48	66	3	5	7	8	10	11	12	14	17
5	1	5	9	14	20	26	33	43	61	2	5	6	8	9	10	11	13	15
6	1	4	8	13	19	24	30	39	56	2	4	6	7	8	9	10	12	14
7	1	4	8	12	17	22	28	37	52	2	4	5	7	8	9	10	11	13
8	1	4	7	11	16	21	26	34	49	2	4	5	6	7	8	9	10	12
9	1	3	7	11	15	20	25	32	46	2	3	5	6	7	8	8	9	11
10	1	3	7	10	14	19	24	31	44	2	3	4	5	6	7	8	9	10
11	1	3	6	10	14	18	23	30	42	2	3	4	5	6	7	7	8	10
12	1	3	6	10	13	17	22	28	40	1	3	4	5	5	6	7	8	9
13	1	3	6	9	13	17	21	27	39	1	3	4	4	5	6	6	7	9
14	1	3	6	9	12	16	20	26	37	1	2	3	4	5	5	6	7	8
15	1	3	5	8	12	15	19	25	36	1	2	3	4	4	5	6	6	7
16	1	2	5	8	11	15	18	24	34	1	2	3	3	4	5	5	6	7
17	1	2	5	8	11	14	17	23	32	1	2	3	3	4	4	5	5	6
18	1	2	4	7	10	13	16	21	30	1	2	2	3	3	4	4	5	6
19	1	2	4	6	9	12	14	19	27	1	1	2	3	3	3	4	4	5
20	0	2	4	6	8	10	13	17	24	1	1	2	2	3	3	3	4	4
21	0	1	3	5	7	9	11	14	20	1	1	1	2	2	2	3	3	3
22	0	1	2	4	5	7	9	11	16	0	1	1	1	2	2	2	2	3
23	0	1	2	3	4	5	6	8	11	0	1	1	1	1	1	1	2	2

FUEL MOISTURE	RATE OF SPREAD: EFFECTIVE MIDFLAME WIND (MI/H)									FLAME LENGTH: EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	3	9	19	30	42	54	67	88	126	5	9	12	15	17	20	22	25	29
3	2	8	17	26	37	48	59	78	111	4	8	11	14	16	18	20	22	25
4	2	7	15	23	33	43	53	70	99	4	7	10	12	14	16	18	20	24
5	2	7	13	21	30	39	48	63	89	4	7	9	11	13	15	16	19	22
6	2	6	12	19	27	35	44	58	82	3	6	8	10	12	14	15	17	20
7	2	6	11	18	25	33	41	53	76	3	6	8	10	11	13	14	16	19
8	1	5	11	17	23	31	38	50	71	3	5	7	9	10	12	13	15	17
9	1	5	10	16	22	29	36	47	67	3	5	7	8	10	11	12	14	16
10	1	5	10	15	21	28	34	45	64	3	5	6	8	9	10	11	13	15
11	1	5	9	14	20	26	33	43	61	2	4	6	7	8	10	11	12	14
12	1	4	9	14	19	25	32	41	59	2	4	6	7	8	9	10	11	13
13	1	4	9	13	19	24	30	40	57	2	4	5	6	7	8	9	10	12
14	1	4	8	13	18	24	29	38	55	2	3	5	6	7	8	9	10	11
15	1	4	8	12	17	23	28	37	52	2	3	4	5	6	7	8	9	11
16	1	4	7	12	16	21	27	35	50	2	3	4	5	6	7	7	8	10
17	1	3	7	11	15	20	25	33	47	1	3	4	5	5	6	7	8	9
18	1	3	6	10	14	19	23	30	43	1	2	3	4	5	5	6	7	8
19	1	3	6	9	13	17	21	28	39	1	2	3	4	4	5	5	6	7
20	1	3	5	8	11	15	19	24	35	1	2	3	3	4	4	5	5	6
21	1	2	4	7	10	13	16	21	29	1	2	2	3	3	3	4	4	5
22	0	2	4	6	8	10	13	16	23	1	1	2	2	2	3	3	3	4
23	0	1	2	4	5	7	9	12	17	0	1	1	1	2	2	2	2	3
24	0	1	1	2	3	4	5	6	9	0	0	1	1	1	1	1	1	2

Ponderosa Pine

Size Class 4

Partial Cut

Tables 3 Through 7

(Corresponds to Photo Series 1-PP-4-PC to 5-PP-4-PC in Maxwell and Ward 1976)

(FIRE BEHAVIOR INFORMATION SCALED FROM NFFL MODELS)

FUEL MOISTURE	RATE OF SPREAD — EFFECTIVE MIDFLAME WIND (MI/H)									FLAME LENGTH — EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	0	1	2	3	4	6	7	9	12	0	1	1	1	1	2	2	2	2
3	0	1	2	3	4	5	6	8	10	0	1	1	1	1	1	2	2	2
4	0	1	2	2	3	4	5	7	9	0	1	1	1	1	1	1	2	2
5	0	1	1	2	3	4	5	6	9	0	1	1	1	1	1	1	2	2
6	0	1	1	2	3	4	5	6	8	0	1	1	1	1	1	1	1	2
7	0	1	1	2	3	3	4	6	8	0	1	1	1	1	1	1	1	2
8	0	1	1	2	3	3	4	5	7	0	0	1	1	1	1	1	1	2
9	0	1	1	2	2	3	4	5	7	0	0	1	1	1	1	1	1	1
10	0	0	1	1	2	3	3	4	6	0	0	1	1	1	1	1	1	1
11	0	0	1	1	1	2	2	3	4	0	0	0	1	1	1	1	1	1
12	0	0	0	1	1	1	1	2	2	0	0	0	0	0	0	0	0	1

TABLE 4--FIRE BEHAVIOR AND CONTROL INFORMATION FOR PHOTO 2-PP TT
(FIRE BEHAVIOR INFORMATION SCALED FROM NFDR MODELS)

FUEL MOISTURE	RATE OF SPREAD: EFFECTIVE MIDFLAME WIND (MI/H)									FLAME LENGTH: EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	1	4	9	14	19	25	31	41	58	2	4	5	7	8	9	10	11	13
3	1	4	8	12	17	22	27	36	51	2	4	5	6	7	8	9	10	12
4	1	3	7	11	15	20	24	32	46	2	3	5	6	7	7	8	9	11
5	1	3	6	10	14	18	22	29	41	2	3	4	5	6	7	8	9	10
6	1	3	6	9	12	16	20	27	38	1	3	4	5	6	6	7	8	9
7	1	3	5	8	11	15	19	25	35	1	3	4	4	5	6	6	7	9
8	1	2	5	8	11	14	18	23	33	1	2	3	4	5	5	6	7	8
9	1	2	5	7	10	13	17	22	31	1	2	3	4	4	5	6	6	7
10	1	2	4	7	10	13	16	21	30	1	2	3	4	4	5	5	6	7
11	0	2	4	7	9	12	15	20	26	1	2	3	3	4	4	5	5	6
12	0	2	4	6	9	12	15	19	27	1	2	3	3	4	4	5	5	6
13	0	2	4	6	9	11	14	18	26	1	2	2	3	3	4	4	5	6
14	0	2	4	6	8	11	13	18	25	1	2	2	3	3	4	4	4	5
15	0	2	4	6	8	10	13	17	24	1	1	2	2	3	3	4	4	5
16	0	2	3	5	8	10	12	16	23	1	1	2	2	3	3	3	4	4
17	0	2	3	5	7	9	12	15	22	1	1	2	2	2	3	3	3	4
18	0	1	3	5	7	9	11	14	20	1	1	2	2	2	2	3	3	4
19	0	1	3	4	6	8	10	13	18	0	1	1	2	2	2	2	3	3
20	0	1	2	4	5	7	9	11	16	0	1	1	1	2	2	2	2	3
21	0	1	2	3	4	6	7	10	14	0	1	1	1	1	2	2	2	2
22	0	1	2	3	4	5	6	8	11	0	1	1	1	1	1	1	2	2
23	0	1	1	2	2	3	4	5	8	0	0	1	1	1	1	1	1	1
24	0	0	1	1	1	2	2	3	4	0	0	0	0	0	0	1	1	1

FUEL MOISTURE	RATE OF SPREAD — EFFECTIVE MIDFLAME WIND (MI/H)									FLAME LENGTH — EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	1	3	5	8	11	14	17	22	30	1	2	3	4	4	5	5	6	7
3	0	2	4	7	9	12	15	19	26	1	2	3	3	4	4	5	5	6
4	0	2	4	6	8	11	13	17	23	1	2	3	3	4	4	4	5	6
5	0	2	4	6	8	10	12	15	21	1	2	2	3	3	4	4	5	5
6	0	2	3	5	7	9	11	14	20	1	2	2	3	3	4	4	4	5
7	0	2	3	5	7	9	11	14	19	1	2	2	3	3	3	4	4	5
8	0	2	3	5	6	8	10	13	18	1	2	2	3	3	3	4	4	5
9	0	1	3	4	6	8	9	12	17	1	1	2	2	3	3	3	4	5
10	0	1	3	4	5	7	8	11	15	1	1	2	2	3	3	3	4	4
11	0	1	2	3	5	6	7	9	13	1	1	2	2	2	3	3	3	4
12	0	1	2	3	4	5	6	7	10	0	1	1	2	2	2	2	3	3
13	0	1	1	2	2	3	3	4	6	0	1	1	1	1	1	1	2	2
14	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0

TABLE 6--FIRE BEHAVIOR AND CONTROL INFORMATION FOR PHOTO 4-PP-
(FIRE BEHAVIOR INFORMATION SCALED FROM NFDR MODELS)

FUEL MOISTURE	RATE OF SPREAD									FLAME LENGTH								
	EFFECTIVE MIDFLAME WIND (MI/H)									EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	1	5	9	15	21	27	34	45	64	2	4	6	7	8	9	10	12	14
3	1	4	8	13	19	24	30	40	56	2	4	5	6	8	8	9	11	13
4	1	4	7	12	17	22	27	35	50	2	3	5	6	7	8	9	10	11
5	1	3	7	11	15	19	24	32	45	2	3	4	5	6	7	8	9	10
6	1	3	6	10	14	18	22	29	42	2	3	4	5	6	7	7	8	10
7	1	3	6	9	13	17	21	27	38	1	3	4	5	5	6	7	8	9
8	1	3	5	8	12	15	19	25	36	1	2	3	4	5	6	6	7	8
9	1	2	5	8	11	15	18	24	34	1	2	3	4	5	5	6	7	8
10	1	2	5	8	11	14	17	23	32	1	2	3	4	4	5	5	6	7
11	1	2	5	7	10	13	17	22	31	1	2	3	3	4	5	5	6	7
12	1	2	4	7	10	13	16	21	30	1	2	3	3	4	4	5	5	6
13	1	2	4	7	9	12	15	20	29	1	2	2	3	4	4	4	5	6
14	0	2	4	7	9	12	15	19	28	1	2	2	3	3	4	4	5	5
15	0	2	4	6	9	11	14	19	27	1	2	2	3	3	3	4	4	5
16	0	2	4	6	8	11	14	18	25	1	1	2	2	3	3	3	4	5
17	0	2	4	6	8	10	13	17	24	1	1	2	2	3	3	3	4	4
18	0	2	3	5	7	9	12	15	22	1	1	2	2	2	3	3	3	4
19	0	1	3	5	7	9	11	14	20	1	1	1	2	2	2	3	3	3
20	0	1	3	4	6	8	9	12	18	0	1	1	1	2	2	2	2	3
21	0	1	2	4	5	6	8	11	15	0	1	1	1	1	2	2	2	2
22	0	1	2	3	4	5	6	8	12	0	1	1	1	1	1	1	2	2

(FIRE BEHAVIOR INFORMATION SCALED FROM NFFL MODELS)

FUEL MOISTURE	RATE OF SPREAD — EFFECTIVE MIDFLAME WIND (MI/H)									FLAME LENGTH — EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	1	3	6	10	13	17	21	27	37	1	3	4	5	6	6	7	8	9
3	1	3	6	8	12	15	18	23	32	1	3	4	4	5	6	6	7	8
4	1	3	5	8	10	13	16	21	28	1	2	3	4	5	5	6	6	7
5	1	2	4	7	9	12	15	19	26	1	2	3	4	4	5	5	6	7
6	0	2	4	6	9	11	14	18	24	1	2	3	4	4	5	5	6	7
7	0	2	4	6	8	11	13	17	23	1	2	3	3	4	4	5	5	6
8	0	2	4	6	8	10	12	16	22	1	2	3	3	4	4	5	5	6
9	0	2	4	5	7	10	12	15	21	1	2	3	3	4	4	5	5	6
10	0	2	3	5	7	9	11	14	19	1	2	2	3	3	4	4	5	6
11	0	2	3	4	6	8	10	12	17	1	2	2	3	3	4	4	4	5
12	0	1	2	4	5	6	8	10	14	1	1	2	2	3	3	3	4	4
13	0	1	2	3	4	5	6	7	10	1	1	1	2	2	2	3	3	3
14	0	0	1	1	2	3	3	4	6	0	1	1	1	1	1	1	2	2

Ponderosa Pine

Size Class 1

Precommercial Thinning

Tables 8 Through 13

(Corresponds to Photo Series 1-PP-1-TH to 6-PP-1-TH in Maxwell and Ward 1976)

FUEL MOISTURE	RATE OF SPREAD — EFFECTIVE MIDFLAME WIND (MI/H)									FLAME LENGTH — EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	1	5	10	16	23	29	37	48	69	2	4	6	7	8	10	11	12	14
3	1	4	9	14	20	26	32	42	60	2	4	5	7	8	9	10	11	13
4	1	4	8	13	18	23	29	38	54	2	4	5	6	7	8	9	10	12
5	1	4	7	11	16	21	26	34	49	2	3	4	6	6	7	8	9	11
6	1	3	7	10	15	19	24	31	45	2	3	4	5	6	7	7	8	10
7	1	3	6	10	14	18	22	29	41	1	3	4	5	5	6	7	8	9
8	1	3	6	9	13	17	21	27	39	1	3	4	4	5	6	6	7	9
9	1	3	5	9	12	16	20	26	37	1	2	3	4	5	5	6	7	8
10	1	3	5	8	11	15	19	24	35	1	2	3	4	4	5	6	6	7
11	1	2	5	8	11	14	18	23	33	1	2	3	4	4	5	5	6	7
12	1	2	5	8	11	14	17	23	32	1	2	3	3	4	4	5	6	6
13	1	2	5	7	10	13	17	22	31	1	2	3	3	4	4	5	5	6
14	1	2	4	7	10	13	16	21	30	1	2	2	3	3	4	4	5	6
15	1	2	4	7	9	12	15	20	28	1	2	2	3	3	4	4	4	5
16	0	2	4	6	9	12	14	19	27	1	1	2	2	3	3	4	4	5
17	0	2	4	6	8	11	14	18	25	1	1	2	2	3	3	3	4	4
18	0	2	3	6	8	10	13	17	24	1	1	2	2	2	3	3	3	4
19	0	2	3	5	7	9	11	15	21	1	1	1	2	2	2	3	3	3
20	0	1	3	4	6	8	10	13	19	0	1	1	2	2	2	2	3	3
21	0	1	2	4	5	7	9	11	16	0	1	1	1	1	2	2	2	2
22	0	1	2	3	4	5	7	9	13	0	1	1	1	1	1	1	2	2
23	0	1	1	2	3	4	5	6	9	0	0	1	1	1	1	1	1	1
24	0	0	1	1	2	2	3	3	5	0	0	0	0	0	0	1	1	1

TABLE 9--FIRE BEHAVIOR AND CONTROL INFORMATION FOR PHOTO 2-PP-1-TH
(FIRE BEHAVIOR INFORMATION SCALED FROM NFDR MODELS)

FUEL MOISTURE	RATE OF SPREAD: EFFECTIVE MIDFLAME WIND (MI/H)									FLAME LENGTH: EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	1	5	10	17	23	30	33	50	71	3	5	7	8	10	11	12	14	16
3	1	5	9	15	20	27	33	44	52	2	4	6	7	9	10	11	12	14
4	1	4	5	13	18	24	30	39	56	2	4	5	7	8	9	10	11	13
5	1	4	7	12	17	22	27	35	50	2	4	5	6	7	8	9	10	12
6	1	3	7	11	15	20	25	32	46	2	3	5	6	7	8	8	9	11
7	1	3	6	10	14	18	23	30	42	2	3	4	5	6	7	8	9	10
8	1	3	5	9	13	17	21	28	40	2	3	4	5	6	6	7	8	10
9	1	3	6	9	12	16	20	26	38	1	3	4	5	5	6	7	8	9
10	1	3	5	8	12	15	19	25	36	1	2	3	4	5	6	6	7	8
11	1	2	5	8	11	15	18	24	34	1	2	3	4	5	5	6	7	8
12	1	2	5	8	11	14	18	23	33	1	2	3	4	4	5	5	6	7
13	1	2	5	7	10	14	17	22	32	1	2	3	3	4	5	5	6	7
14	1	2	5	7	10	13	16	22	31	1	2	3	3	4	4	5	5	6
15	1	2	4	7	10	13	16	21	29	1	2	2	3	4	4	4	5	6
16	1	2	4	7	9	12	15	20	28	1	2	2	3	3	4	4	5	5
17	0	2	4	6	9	11	14	18	26	1	1	2	3	3	3	4	4	5
18	0	2	4	6	8	10	13	17	24	1	1	2	2	3	3	3	4	4
19	0	2	3	5	7	9	12	16	22	1	1	2	2	2	3	3	3	4
20	0	1	3	5	6	8	10	14	20	1	1	1	2	2	2	3	3	3
21	0	1	2	4	5	7	9	12	17	0	1	1	1	2	2	2	2	3

TABLE 10--FIRE BEHAVIOR AND CONTROL INFORMATION FOR [illegible]
(FIRE BEHAVIOR INFORMATION SCALED FROM NFDR MODELS)

FUEL MOISTURE	RATE OF SPREAD									FLAME LENGTH								
	EFFECTIVE MIDFLAME WIND (MI/H)									EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	1	5	11	17	24	31	39	51	72	3	6	8	9	11	12	14	15	18
3	1	5	9	15	21	27	34	45	64	3	5	7	9	10	11	13	14	17
4	1	4	8	13	19	24	30	40	57	2	5	6	8	9	10	11	13	15
5	1	4	8	12	17	22	28	36	51	2	4	6	7	8	9	10	12	14
6	1	3	7	11	15	20	25	33	47	2	4	5	7	8	9	10	11	13
7	1	3	6	10	14	19	23	31	44	2	4	5	6	7	8	9	10	12
8	1	3	6	10	13	18	22	29	41	2	3	5	6	7	7	8	9	11
9	1	3	6	9	13	17	21	27	39	2	3	4	5	6	7	8	9	10
10	1	3	5	9	12	16	20	26	37	2	3	4	5	6	7	7	8	10
11	1	3	5	8	12	15	19	25	35	1	3	4	5	5	6	7	8	9
12	1	2	5	8	11	15	18	24	34	1	3	3	4	5	6	6	7	8
13	1	2	5	8	11	14	17	23	33	1	2	3	4	5	5	6	7	8
14	1	2	5	7	10	13	17	22	31	1	2	3	4	4	5	5	6	7
15	1	2	4	7	10	13	16	21	30	1	2	3	3	4	5	5	6	7
16	1	2	4	7	9	12	15	20	29	1	2	3	3	4	4	5	5	6
17	0	2	4	6	9	12	14	19	27	1	2	2	3	3	4	4	5	6
18	0	2	4	6	8	11	13	18	25	1	2	2	3	3	3	4	4	5
19	0	2	3	5	7	10	12	16	23	1	1	2	2	3	3	3	4	4
20	0	1	3	5	7	9	11	14	20	1	1	2	2	2	3	3	3	4
21	0	1	3	4	6	7	9	12	17	1	1	1	2	2	2	2	3	3
22	0	1	2	3	4	6	7	9	13	0	1	1	1	2	2	2	2	3
23	0	1	1	2	3	4	5	7	9	0	1	1	1	1	1	1	2	2
24	0	0	1	1	2	2	3	4	5	0	0	0	0	1	1	1	1	1

TABLE 11--FIRE BEHAVIOR AND CONTROL INFORMATION FOR PHOTO 4-PP-1-TH
(FIRE BEHAVIOR INFORMATION SCALED FROM NFFL MODELS)

FUEL MOISTURE	RATE OF SPREAD									FLAME LENGTH								
	EFFECTIVE MIDFLAME WIND (MI/H)									EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	0	2	5	7	10	12	15	20	27	1	2	3	3	4	4	5	5	6
3	0	2	4	6	9	11	13	17	23	1	2	2	3	3	4	4	5	5
4	0	2	4	5	7	9	12	15	21	1	2	2	3	3	3	4	4	5
5	0	2	3	5	7	9	11	14	19	1	2	2	3	3	3	4	4	5
6	0	2	3	5	6	8	10	13	18	1	1	2	2	3	3	3	4	4
7	0	1	3	4	5	8	9	12	17	[illegible]	1	2	2	3	3	3	4	4
8	0	1	3	4	6	7	[illegible]	11	16	1	1	2	2	3	3	3	4	4
9	0	1	3	4	[illegible]	7	8	11	15	1	1	2	2	2	3	3	3	4
10	0	1	2	3	5	6	7	10	13	1	1	2	2	2	3	3	3	4
11	0	1	2	3	4	5	6	8	12	0	1	1	2	2	2	2	3	3
12	0	1	1	2	3	4	5	6	8	0	1	1	1	2	2	2	2	2
13	0	0	1	1	2	2	3	3	5	0	0	1	1	1	1	1	1	1

FUEL MOISTURE	RATE OF SPREAD — EFFECTIVE MIDFLAME WIND (MI/H)									FLAME LENGTH — EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	1	4	9	13	17	22	27	34	47	2	4	5	7	8	8	9	10	12
3	1	4	7	11	15	19	23	30	41	2	4	5	6	7	8	8	9	11
4	1	3	6	10	14	17	20	26	36	2	3	4	5	6	7	7	8	10
5	1	3	6	9	12	15	19	24	33	2	3	4	5	6	6	7	8	9
6	1	3	5	8	11	14	17	22	31	1	3	4	5	5	6	7	7	9
7	1	3	5	8	10	13	16	21	29	1	3	4	5	5	6	6	7	8
8	1	2	5	7	10	13	16	20	28	1	3	4	4	5	6	6	7	8
9	1	2	5	7	10	12	15	19	26	1	3	4	4	5	6	6	7	8
10	1	2	4	7	9	11	14	18	25	1	2	3	4	5	5	6	7	8
11	0	2	4	6	8	11	13	17	23	1	2	3	4	4	5	5	6	7
12	0	2	4	5	7	9	11	15	20	1	2	3	4	4	5	5	6	6
13	0	2	3	5	6	8	10	12	17	1	2	2	3	3	4	4	5	6
14	0	1	2	3	5	6	7	9	13	1	1	2	2	3	3	3	4	4
15	0	1	1	2	3	3	4	5	7	0	1	1	1	2	2	2	2	3
16	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0

TABLE 13--FIRE BEHAVIOR AND CONTROL INFORMATION FOR PHOTO 6-PP-1-TH
(FIRE BEHAVIOR INFORMATION SCALED FROM NFDR MODELS)

FUEL MOISTURE	RATE OF SPREAD, EFFECTIVE MIDFLAME WIND (MI/H)									FLAME LENGTH, EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	2	7	15	24	33	43	54	71	101	5	9	12	15	18	20	22	25	30
3	2	7	13	21	29	38	48	63	89	4	8	11	14	16	18	20	23	27
4	2	6	12	19	26	34	43	56	80	4	7	10	13	15	17	19	21	25
5	1	5	11	17	24	31	39	51	72	4	7	9	12	14	15	17	19	23
6	1	5	10	16	22	28	35	46	66	3	6	9	11	13	14	16	18	21
7	1	4	9	14	20	26	33	43	61	3	6	8	10	12	13	15	16	19
8	1	4	9	13	19	25	31	40	57	3	5	8	9	11	12	14	15	18
9	1	4	8	13	18	23	29	38	54	3	5	7	9	10	11	13	14	17
10	1	4	8	12	17	22	28	36	51	3	5	7	8	9	11	12	13	16
11	1	4	7	12	16	21	26	35	49	2	4	6	8	9	10	11	12	15
12	1	3	7	11	16	20	25	33	47	2	4	6	7	8	9	10	12	14
13	1	3	7	11	15	20	24	32	46	2	4	5	7	8	9	10	11	13
14	1	3	7	10	14	19	24	31	44	2	4	5	6	7	8	9	10	12
15	1	3	6	10	14	18	23	30	42	2	3	5	6	7	7	8	9	11
16	1	3	6	9	13	17	21	28	40	2	3	4	5	6	7	8	9	10
17	1	3	6	9	12	16	20	26	38	1	3	4	5	6	6	7	8	9
18	1	3	5	8	11	15	19	25	35	1	2	3	4	5	6	6	7	8
19	1	2	5	7	10	14	17	22	32	1	2	3	4	4	5	5	6	7
20	1	2	4	7	9	12	15	20	28	1	2	3	3	4	4	5	5	6
21	0	2	4	6	8	10	13	17	24	1	2	2	3	3	4	4	4	5
22	0	1	3	4	6	8	10	13	19	1	1	2	2	2	3	3	3	4

Ponderosa Pine and Associated Species

Size Class 4

Partial Cut

Tables 14 Through 21

(Corresponds to Photo Series 1-PP&ASSOC-4-PC to 8-PP&ASSOC-4-PC in Maxwell and Ward 1976)

TABLE 14--FIRE BEHAVIOR AND CONTROL INFORMATION FOR PHOTO 1-PP&ASSOC-4-PC
(FIRE BEHAVIOR INFORMATION SCALED FROM NFFL MODELS)

FUEL MOISTURE	RATE OF SPREAD									FLAME LENGTH								
	EFFECTIVE MIDFLAME WIND (MI/H)									EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	0	2	4	6	8	10	12	16	22	1	2	2	3	3	3	4	4	5
3	0	2	3	5	7	9	11	14	19	1	1	2	2	3	3	3	4	4
4	0	1	3	4	6	8	9	12	17	1	1	2	2	2	3	3	3	4
5	0	1	3	4	6	7	9	11	16	1	1	2	2	2	3	3	3	4
6	0	1	2	4	5	7	8	11	15	1	1	2	2	2	2	3	3	4
7	0	1	2	4	5	6	8	10	14	1	1	1	2	2	2	3	3	3
8	0	1	2	3	5	6	7	9	13	1	1	1	2	2	2	3	3	3
9	0	1	2	3	4	6	7	9	12	0	1	1	2	2	2	2	3	3
10	0	1	2	3	4	5	6	8	11	0	1	1	1	2	2	2	2	3
11	0	1	1	2	3	4	5	6	9	0	1	1	1	1	2	2	2	2
12	0	0	1	2	2	3	3	4	6	0	1	1	1	1	1	1	1	2
13	0	0	0	1	1	1	1	2	2	0	0	0	0	0	1	1	1	1

FUEL MOISTURE	RATE OF SPREAD: EFFECTIVE MIDFLAME WIND (MI/H)									FLAME LENGTH: EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

TABLE 16--FIRE BEHAVIOR AND CONTROL INFORMATION FOR PHOTO 3-PP&ASSOC-4-PC
(FIRE BEHAVIOR INFORMATION SCALED FROM NFFL MODELS)

FUEL MOISTURE	RATE OF SPREAD: EFFECTIVE MIDFLAME WIND (MI/H)									FLAME LENGTH: EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	1	3	6	8	12	15	18	23	32	1	2	3	4	5	5	6	6	8
3	1	2	5	7	10	13	15	20	28	1	2	3	4	4	5	5	6	7
4	0	2	4	6	9	11	14	18	24	1	2	3	3	4	4	5	5	6
5	0	2	4	6	8	10	13	16	22	1	2	3	3	4	4	4	5	6
6	0	2	4	6	8	10	12	15	21	1	2	2	3	3	4	4	5	5
7	0	2	3	5	7	9	11	14	20	1	2	2	3	3	4	4	5	5
8	0	2	3	5	7	9	11	14	19	1	2	2	3	3	4	4	4	5
9	0	2	3	5	6	8	10	13	18	1	2	2	3	3	3	4	4	5
10	0	1	3	4	6	7	9	12	16	1	1	2	2	3	3	4	4	5
11	0	1	2	4	5	6	8	10	14	1	1	2	2	3	3	3	3	4
12	0	1	2	3	4	5	6	8	11	1	1	1	2	2	2	3	3	3
13	0	1	1	2	3	3	4	5	7	0	1	1	1	1	2	2	2	2
14	0	0	0	1	1	1	1	2	2	0	0	0	0	0	1	1	1	1

TABLE 17--FIRE BEHAVIOR AND CONTROL INFORMATION [illegible]
(FIRE BEHAVIOR INFORMATION SCALED FROM NFFL MODELS)

FUEL MOISTURE	RATE OF SPREAD: EFFECTIVE MIDFLAME WIND (MI/H) 0	2	4	6	8	10	12	14	16	FLAME LENGTH: EFFECTIVE MIDFLAME WIND (MI/H) 0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	1	3	6	8	12	15	18	23	32	1	2	3	4	5	5	6	6	8
3	1	2	5	7	10	13	15	20	27	1	2	3	4	4	5	5	6	7
4	0	2	4	6	9	11	14	18	24	1	2	3	3	4	4	5	5	6
5	0	2	4	6	8	10	13	16	22	1	2	3	3	4	4	4	5	6
6	0	2	4	5	7	10	12	15	21	1	2	2	3	3	4	4	5	5
7	0	2	3	5	7	9	11	14	20	1	2	2	3	3	4	4	5	5
8	0	2	3	5	7	9	11	14	19	1	2	2	3	3	4	4	4	5
9	0	2	3	5	6	8	10	13	18	1	2	2	3	3	3	4	4	5
10	0	1	3	4	6	7	9	12	16	1	1	2	2	3	3	3	4	5
11	0	1	2	4	5	6	8	10	14	1	1	2	2	3	3	3	3	4
12	0	1	2	3	4	5	6	8	11	1	1	1	2	2	2	3	3	3
13	0	1	1	2	3	3	4	5	7	0	1	1	1	1	2	2	2	2
14	0	0	0	1	1	1	1	2	2	0	0	0	0	0	1	1	1	1

TABLE 18--FIRE BEHAVIOR AND CONTROL INFORMATION FOR PHOTO 5-PPRASSOC-4-PC
(FIRE BEHAVIOR INFORMATION SCALED FROM NFFL MODELS)

FUEL MOISTURE	RATE OF SPREAD: EFFECTIVE MIDFLAME WIND (MI/H)									FLAME LENGTH: EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	1	3	5	8	10	13	16	21	29	1	2	3	4	4	5	5	6	7
3	0	2	4	7	9	11	14	18	25	1	2	3	3	4	4	5	5	6
4	0	2	4	6	8	10	12	16	22	1	2	2	3	3	4	4	5	5
5	0	2	3	5	7	9	11	15	20	1	2	2	3	3	4	4	4	5
6	0	2	3	5	7	9	11	14	19	1	2	2	3	3	3	4	4	5
7	0	2	3	5	6	8	10	13	18	1	2	2	3	3	3	4	4	5
8	0	1	3	4	6	8	10	12	17	1	1	2	2	3	3	3	4	5
9	0	1	3	4	6	7	9	12	16	1	1	2	2	3	3	3	4	4
10	0	1	2	4	5	7	8	10	14	1	1	2	2	2	3	3	3	4
11	0	1	2	3	4	6	7	9	12	1	1	2	2	2	2	3	3	3
12	0	1	2	2	3	4	5	7	9	0	1	1	1	2	2	2	2	3
13	0	0	1	1	2	3	3	4	5	0	1	1	1	1	1	1	1	2
14	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0

(FIRE BEHAVIOR INFORMATION SCALED FROM NFFL MODELS)

FUEL MOISTURE	RATE OF SPREAD — EFFECTIVE MIDFLAME WIND (MI/H)									FLAME LENGTH — EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	1	3	6	9	13	16	20	25	35	1	3	4	5	5	6	6	7	8
3	1	3	5	8	11	14	17	22	30	1	2	3	4	5	5	6	6	7
4	1	2	5	7	10	12	15	19	27	1	2	3	4	4	5	5	6	7
5	0	2	4	6	9	11	14	18	24	1	2	3	3	4	4	5	5	6
6	0	2	4	5	8	10	13	16	23	1	2	3	3	4	4	5	5	6
7	0	2	4	6	8	10	12	16	22	1	2	3	3	4	4	4	5	6
8	0	2	4	5	7	9	12	15	21	1	2	3	3	4	4	4	5	6
9	0	2	3	5	7	9	11	14	19	1	2	2	3	3	4	4	5	5
10	0	2	3	5	6	8	10	13	18	1	2	2	3	3	4	4	4	5
11	0	1	3	4	6	7	9	11	16	1	2	2	2	3	3	4	4	5
12	0	1	2	3	5	6	7	9	13	1	1	2	2	2	3	3	3	4
13	0	1	2	2	3	4	5	6	9	0	1	1	2	2	2	2	2	3
14	0	0	1	1	1	2	2	3	4	0	0	1	1	1	1	1	1	1

TABLE 20--FIRE BEHAVIOR AND CONTROL INFORMATION FOR PHOTO 7-PP&ASSOC-4-PC
(FIRE BEHAVIOR INFORMATION SCALED FROM NFFL MODELS)

FUEL MOISTURE	RATE OF SPREAD: EFFECTIVE MIDFLAME WIND (MI/H)									FLAME LENGTH: EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	1	3	5	8	11	14	17	22	31	1	2	3	4	4	5	6	6	7
3	0	2	5	7	10	12	15	19	26	1	2	3	3	4	4	5	5	6
4	0	2	4	6	8	11	13	17	23	1	2	3	3	4	4	4	5	6
5	0	2	4	6	8	10	12	16	21	1	2	2	3	3	4	4	5	5
6	0	2	3	5	7	9	11	15	20	1	2	2	3	3	4	4	4	5
7	0	2	3	5	7	9	11	14	19	1	2	2	3	3	4	4	4	5
8	0	2	3	5	7	8	10	13	18	1	2	2	3	3	3	4	4	5
9	0	1	3	4	6	8	10	12	17	1	2	2	3	3	3	4	4	5
10	0	1	3	4	6	7	9	11	15	1	1	2	2	3	3	3	4	4
11	0	1	2	3	5	6	7	10	13	1	1	2	2	2	3	3	3	4
12	0	1	2	3	4	5	6	7	10	0	1	1	2	2	2	2	3	3
13	0	1	1	2	2	3	4	5	6	0	1	1	1	1	1	2	2	2
14	0	0	0	0	1	1	1	1	2	0	0	0	0	0	0	0	0	1

FUEL MOISTURE	RATE OF SPREAD — EFFECTIVE MIDFLAME WIND (MI/H)									FLAME LENGTH — EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	1	5	10	16	22	28	35	47	66	3	5	7	9	11	12	13	15	18
3	1	4	9	14	19	25	31	41	58	3	5	7	8	10	11	12	14	16
4	1	4	8	12	17	22	28	37	52	2	4	6	8	9	10	11	13	15
5	1	3	7	11	16	20	25	33	47	2	4	6	7	8	9	10	12	14
6	1	3	6	10	14	19	23	30	43	2	4	5	6	8	8	9	11	13
7	1	3	6	9	13	17	21	28	40	2	3	5	6	7	8	9	10	12
8	1	3	6	9	12	16	20	26	37	2	3	4	6	6	7	8	9	11
9	1	3	5	8	12	15	19	25	35	2	3	4	5	6	7	8	9	10
10	1	2	5	8	11	14	18	24	34	1	3	4	5	6	6	7	8	9
11	1	2	5	8	11	14	17	23	32	1	3	4	4	5	6	7	7	9
12	1	2	5	7	10	13	17	22	31	1	2	3	4	5	6	6	7	8
13	1	2	4	7	10	13	16	21	30	1	2	3	4	5	5	6	7	8
14	1	2	4	7	9	12	15	20	29	1	2	3	4	4	5	5	6	7
15	0	2	4	6	9	12	15	19	28	1	2	3	3	4	4	5	6	7
16	0	2	4	6	9	11	14	18	26	1	2	3	3	4	4	5	5	6
17	0	2	4	6	8	11	13	17	25	1	2	2	3	3	4	4	5	6
18	0	2	3	5	8	10	12	16	23	1	1	2	3	3	3	4	4	5
19	0	2	3	5	7	9	11	15	21	1	1	2	2	3	3	3	4	4
20	0	1	3	4	6	8	10	13	18	1	1	2	2	2	3	3	3	4
21	0	1	2	4	5	7	8	11	16	0	1	1	2	2	2	2	3	3
22	0	1	2	3	4	5	7	9	12	0	1	1	1	1	2	2	2	2
23	0	1	1	2	3	4	5	6	9	0	1	1	1	1	1	1	1	2
24	0	0	1	1	2	2	2	3	5	0	0	0	0	1	1	1	1	1

Lodgepole Pine

Size Class 3

Clearcut

Table 22

(Corresponds to Photo Series 1-LP-3-CC in Maxwell and Ward 1976)

(FIRE BEHAVIOR INFORMATION SCALED FROM NFFL MODELS)

FUEL MOISTURE	RATE OF SPREAD: EFFECTIVE MIDFLAME WIND (MI/H)									FLAME LENGTH: EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	0	2	4	6	9	11	14	18	24	1	2	2	3	3	4	4	5	5
3	0	2	4	5	7	10	12	15	21	1	2	2	3	3	3	4	4	5
4	0	2	3	5	7	8	10	13	18	1	1	2	2	3	3	3	4	4
5	0	1	3	4	6	8	10	12	17	1	1	2	2	3	3	3	3	4
6	0	1	3	4	6	7	9	12	16	1	1	2	2	2	3	3	3	4
7	0	1	3	4	5	7	9	11	15	1	1	2	2	2	3	3	3	4
8	0	1	2	4	5	7	8	10	14	1	1	2	2	2	3	3	3	4
9	0	1	2	3	5	6	7	10	13	1	1	2	2	2	2	3	3	3
10	0	1	2	3	4	5	7	8	12	0	1	1	2	2	2	2	3	3
11	0	1	2	3	3	4	5	7	10	0	1	1	1	2	2	2	2	3
12	0	1	1	2	2	3	4	5	7	0	1	1	1	1	1	2	2	2
13	0	0	1	1	1	1	2	2	3	0	0	0	1	1	1	1	1	1

Lodgepole Pine

Size Class 3

Partial Cut

Tables 23 Through 27

(Corresponds to Photo Series 1-LP-3-PC to 5-LP-3-PC in Maxwell and Ward 1976)

... AND CONTROL INFORMATION FOR PHOTO 1-LP-3-PC
(FIRE BEHAVIOR INFORMATION SCALED FROM NFFL MODELS)

FUEL MOISTURE	RATE OF SPREAD									FLAME LENGTH								
	EFFECTIVE MIDFLAME WIND (MI/H)									EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	0	1	3	4	5	7	8	11	15	0	1	1	2	2	2	2	3	3
3	0	1	2	3	5	6	7	9	13	0	1	1	1	2	2	2	2	3
4	0	1	2	3	4	5	6	8	11	0	1	1	1	1	2	2	2	2
5	0	1	2	3	4	5	6	8	11	0	1	1	1	1	2	2	2	2
6	0	1	2	3	4	5	6	7	10	0	1	1	1	1	2	2	2	2
7	0	1	2	2	3	4	5	7	9	0	1	1	1	1	1	2	2	2
8	0	1	1	2	3	4	5	6	9	0	1	1	1	1	1	2	2	2
9	0	1	1	2	3	4	5	6	8	0	1	1	1	1	1	1	2	2
10	0	1	1	2	2	3	4	5	7	0	1	1	1	1	1	1	1	2
11	0	0	1	1	2	2	3	4	5	0	0	1	1	1	1	1	1	1
12	0	0	1	1	1	1	2	2	3	0	0	0	0	1	1	1	1	1
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

TABLE 24--FIRE BEHAVIOR AND CONTROL INFORMATION FOR PHOTO 2-LP-3-PC
(FIRE BEHAVIOR INFORMATION SCALED FROM NFFL MODELS)

FUEL MOISTURE	RATE OF SPREAD									FLAME LENGTH								
	EFFECTIVE MIDFLAME WIND (MI/H)									EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	0	2	5	7	10	12	15	19	27	1	2	3	3	4	4	5	5	6
3	0	2	4	6	8	10	13	16	23	1	2	2	3	3	4	4	5	5
4	0	2	3	5	7	9	11	15	20	1	2	2	3	3	3	4	4	5
5	0	2	3	5	7	9	10	13	19	1	1	2	2	3	3	3	4	5
6	0	2	3	5	6	8	10	13	17	1	1	2	2	3	3	3	4	4
7	0	1	3	4	6	8	9	12	17	1	1	2	2	3	3	3	4	4
8	0	1	3	4	6	7	9	11	16	1	1	2	2	3	3	3	4	4
9	0	1	2	4	5	7	8	11	15	1	1	2	2	2	3	3	3	4
10	0	1	2	3	5	6	7	9	13	1	1	2	2	2	2	3	3	4
11	0	1	2	3	4	5	6	8	11	0	1	1	2	2	2	2	3	3
12	0	1	1	2	3	4	5	6	8	0	1	1	1	1	2	2	2	2
13	0	0	1	1	2	2	2	3	4	0	0	1	1	1	1	1	1	1

FUEL MOISTURE	RATE OF SPREAD — EFFECTIVE MIDFLAME WIND (MI/H)									FLAME LENGTH — EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	1	4	8	13	18	23	29	38	54	2	4	6	7	8	9	10	12	14
3	1	3	7	11	16	21	26	34	48	2	4	5	6	7	8	9	11	12
4	1	3	6	10	14	18	23	30	43	2	3	5	6	7	8	8	10	11
5	1	3	6	9	13	17	21	27	39	2	3	4	5	6	7	8	9	10
6	1	3	5	8	12	15	19	25	35	1	3	4	5	6	6	7	8	10
7	1	2	5	8	11	14	17	23	33	1	3	4	5	5	6	7	8	9
8	1	2	5	7	10	13	16	21	31	1	2	3	4	5	6	6	7	8
9	1	2	4	7	9	12	15	20	29	1	2	3	4	5	5	6	6	8
10	0	2	4	6	9	12	15	19	28	1	2	3	4	4	5	5	6	7
11	0	2	4	6	9	11	14	19	26	1	2	3	3	4	5	5	6	7
12	0	2	4	6	8	11	14	18	25	1	2	3	3	4	4	5	5	6
13	0	2	4	6	8	11	13	17	24	1	2	2	3	3	4	4	5	6
14	0	2	3	6	8	10	13	17	24	1	2	2	3	3	4	4	5	5
15	0	2	3	5	7	10	12	16	23	1	1	2	3	3	3	4	4	5
16	0	2	3	5	7	9	11	15	21	1	1	2	2	3	3	3	4	5
17	0	1	3	5	7	9	11	14	20	1	1	2	2	3	3	3	4	4
18	0	1	3	4	6	8	10	13	19	1	1	2	2	2	3	3	3	4
19	0	1	3	4	6	7	9	12	17	1	1	1	2	2	2	2	3	3
20	0	1	2	4	5	6	8	11	15	0	1	1	1	2	2	2	2	3
21	0	1	2	3	4	5	7	9	13	0	1	1	1	1	2	2	2	2
22	0	1	1	2	3	4	5	7	10	0	1	1	1	1	1	1	2	2
23	0	1	1	2	2	3	4	5	7	0	0	1	1	1	1	1	1	1
24	0	0	1	1	1	2	2	3	4	0	0	0	0	0	0	1	1	1

TABLE 26--FIRE BEHAVIOR AND CONTROL INFORMATION FOR PHOTO 4-LP-3-PC
(FIRE BEHAVIOR INFORMATION SCALED FROM NFDR MODELS)

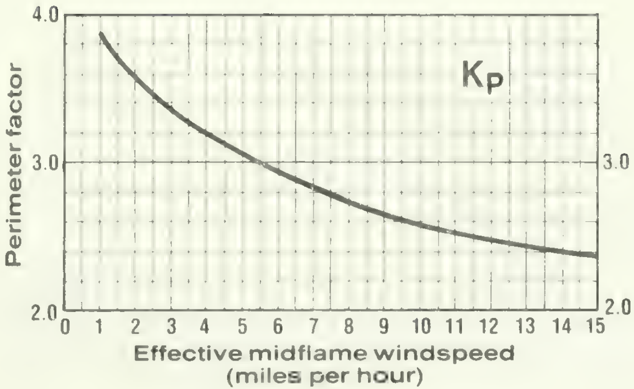
FUEL MOISTURE	RATE OF SPREAD									FLAME LENGTH								
	EFFECTIVE MIDFLAME WIND (MI/H)									EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	1	5	11	17	24	31	38	50	72	3	6	9	11	13	15	16	18	22
3	1	5	9	15	21	27	34	44	63	3	6	8	10	12	13	15	17	20
4	1	4	8	13	19	24	30	40	56	3	5	7	9	11	12	13	15	18
5	1	4	8	12	17	22	27	36	51	3	5	7	8	10	11	12	14	16
6	1	3	7	11	15	20	25	33	47	2	5	6	8	9	10	11	13	15
7	1	3	6	10	14	19	23	30	43	2	4	6	7	8	9	10	12	14
8	1	3	6	9	13	17	22	28	40	2	4	5	7	8	9	10	11	13
9	1	3	6	9	13	16	20	27	38	2	4	5	6	7	8	9	10	12
10	1	3	5	9	12	16	20	26	36	2	3	5	6	7	8	8	10	11
11	1	3	5	8	11	15	19	25	35	2	3	4	5	5	7	8	9	11
12	1	2	5	8	11	14	18	24	34	2	3	4	5	6	7	7	8	10
13	1	2	5	8	11	14	17	23	32	1	3	4	5	6	6	7	8	9
14	1	2	5	7	10	13	17	22	31	1	3	4	4	5	6	6	7	9
15	1	2	4	7	10	13	16	21	30	1	2	3	4	5	5	6	7	8
16	1	2	4	7	9	12	15	20	28	1	2	3	4	4	5	5	6	7
17	0	2	4	6	9	11	14	19	27	1	2	3	3	4	5	5	6	7
18	0	2	4	6	8	11	13	17	25	1	2	2	3	4	4	4	5	6
19	0	2	3	5	7	10	12	16	22	1	2	2	3	3	4	4	4	5
20	0	1	3	5	7	9	11	14	20	1	1	2	2	3	3	3	4	5
21	0	1	2	4	6	7	9	12	17	1	1	2	2	2	3	3	3	4
22	0	1	2	3	4	6	7	9	13	0	1	1	2	2	2	2	3	3

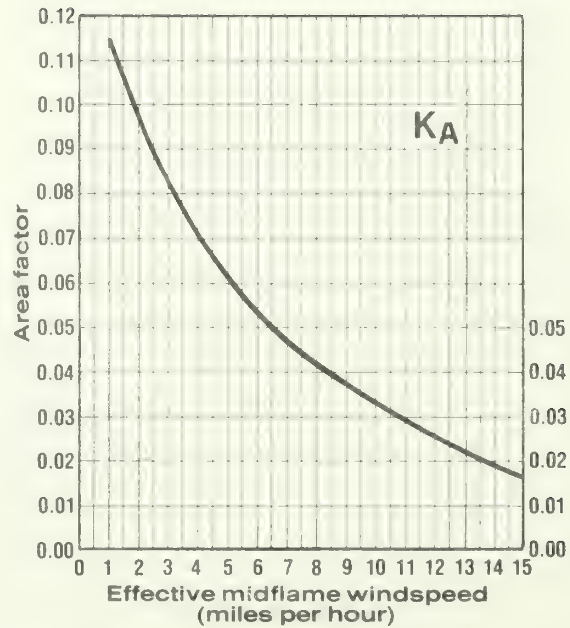
FUEL MOISTURE	RATE OF SPREAD									FLAME LENGTH								
	EFFECTIVE MIDFLAME WIND (MI/H)									EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	1	3	5	8	11	14	18	23	31	1	2	3	4	5	5	6	6	7
3	0	2	5	7	10	12	15	19	27	1	2	3	3	4	4	5	6	6
4	0	2	4	6	9	11	13	17	24	1	2	3	3	4	4	4	5	6
5	0	2	4	6	8	10	12	16	22	1	2	2	3	3	4	4	5	5
6	0	2	3	5	7	9	11	15	20	1	2	2	3	3	4	4	5	5
7	0	2	3	5	7	9	11	14	19	1	2	2	3	3	4	4	4	5
8	0	2	3	5	7	8	10	13	18	1	2	2	3	3	3	4	4	5
9	0	2	3	5	6	8	10	12	17	1	2	2	3	3	3	4	4	5
10	0	1	3	4	6	7	9	11	16	1	1	2	2	3	3	3	4	4
11	0	1	2	4	5	6	8	10	13	1	1	2	2	2	3	3	3	4
12	0	1	2	3	4	5	6	8	11	0	1	1	2	2	2	2	3	3
13	0	1	1	2	2	3	4	5	7	0	1	1	1	1	1	2	2	2
14	0	0	0	0	1	1	1	1	2	0	0	0	0	0	0	0	1	1

Appendix 1

Fire Perimeter and Area Calculation Graphs and Formulas

(Adapted from Fire Behavior Officer's Field Reference, National Interagency Fire Training Center, Marana, Arizona)





P = Perimeter (chains)

$$P = K_P D = K_P(R \times T)$$

A = Area (acres)

$$A = K_A D^2 = K_A(R \times T)^2$$

WHERE:

K_P = Perimeter factor
R = Rate of spread (chains per hour)
T = Time (hour); 1-hour maximum
K_A = Area factor
D = R x T; spread distance (chains)

Appendix 2

Resistance to control ratings, flame length adjustment factor, slope adjustment factor, and conversion of resistance to control rating values to chains per hour of line constructed by one person

The resistance to control rating (table 28) times flame length adjustment factor (table 29) times slope adjustment factor (table 30) equals the adjusted rating. Use table 31 to convert adjusted rating to actual resistance to control.

Table 28--Fuel resistance to control ratings by photo number[1]

PHOTO NUMBER	RATING	PHOTO NUMBER	RATING
1-PP-4-CC	5	1-PP&ASSOC-4-PC	4
2-PP-4-CC	8	2-PP&ASSOC-4-PC	3
		3-PP&ASSOC-4-PC	9
1-PP-4-PC	2	4-PP&ASSOC-4-PC	5
2-PP-4-PC	4	5-PP&ASSOC-4-PC	6
3-PP-4-PC	4	6-PP&ASSOC-4-PC	7
4-PP-4-PC	6	7-PP&ASSOC-4-PC	9
5-PP-4-PC	6	8-PP&ASSOC-4-PC	9
1-PP-1-TH	5	1-LP-3-CC	4
2-PP-1-TH	7		
3-PP-1-TH	8	1-LP-3-PC	2
4-PP-1-TH	6	2-LP-3-PC	4
5-PP-1-TH	6	3-LP-3-PC	4
6-PP-1-TH	9	4-LP-3-PC	6
		5-LP-3-PC	8

[1] Ratings derived from matrix by Wayne G. Maxwell (on file at Pacific Northwest Forest and Range Experiment Station, Portland, Oregon).

Table 29--Flame length adjustment factor

Flame length (feet)	0-4	5-8	9-12	13+
Adjustment factor	1	1.5	2.0	3.0

Table 30--Slope adjustment factor

Slope (percent)	0-30	31-60	61-75	75+
Adjustment factor	1	1.2	1.5	1.9

Table 31--Conversion of rating values to chains per hour of line constructed by 1 person

Adjusted rating values	Chains per hour	Adjusted rating values	Chains per hour
1	12.00	13	0.92
2	6.00	14	.86
3	4.00	15	.80
4	3.00	16	.75
5	2.40	17	.71
6	2.00	18	.67
7	1.70	19	.63
8	1.50	20	.60
9	1.30	25	.48
10	1.20	30	.40
11	1.10	35	.34
12	1.00	40	.30

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PREDICTIONS OF FIRE BEHAVIOR AND RESISTANCE TO CONTROL

FOR USE WITH PHOTO SERIES FOR THE DOUGLAS-FIR—HEMLOCK TYPE AND THE COASTAL DOUGLAS-FIR—HARDWOOD TYPE

DAVID V. SANDBERG
FRANKLIN R. WARD

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This publication presents tables on the behavior of fire and the resistance of fuels to control. The information is to be used with the photos in the publication, "Photo Series for Quantifying Forest Residues in the Coastal Douglas-fir--Hemlock Type, Coastal Douglas-fir--Hardwood Type" (USDA For. Serv. Gen. Tech. Rep. PNW-51, 1976, by Wayne G. Maxwell and Franklin R. Ward).

KEYWORDS: Fire behavior (forest), fire management, fire spread.

Metric Conversion

To change	to	multiply by:
Miles per hour	kilometers per hour	1.6093
Chains	meters	20.12
Feet	meters	0.3048
Acres	hectares	0.4047

Species List

Douglas-fir	*Pseudotsuga menziesii* (Mirb.) Franco
ponderosa pine	*Pinus ponderosa* Dougl. ex Laws.
western hemlock	*Tsuga heterophylla* (Raf.) Sarg.

Timber harvest and silvicultural practices--as well as natural phenomena, such as windthrow, ice damage, and wildfire--often leave undesirable amounts of forest residues. The forest manager must set limits on the amount of residues and fire hazard that are consistent with resource management objectives.

Photo series have been published as an inventory tool to assess fuel loadings by size class in several forest types. The photos are used to translate visual images to quantities (tons per acre) so the manager can describe the residue that should be retained to meet environmental concerns and goals of a particular specialty. The photos also provide a starting point for assessing fire hazard.

This publication presents tables for predicting rate of fire spread, flame length, and resistance of fuel to control for each residue condition depicted by the photo series for the coastal Douglas-fir--hemlock and coastal Douglas-fir--hardwood types (Maxwell and Ward 1976). Fire behavior estimates are based solely on measured fuel loadings in the 1/4- to 3-inch diameter range. All other inputs to a mathematical fire spread model (Rothermel 1972), including depth of fuel bed and 1-hour timelag (0- to 1/4-inch diameter) loading, are generated by assuming similarity of the fuel bed to a stylized fuel model. Packing and surface-to-volume ratios were derived by interpolation between models. Foliage and litter loadings are reflected in the 1-hour timelag fuel loading. No live or coarse (greater than 3-inch diameter) fuels are considered.

Two sets of fuel models are in widespread use for fire planning and hazard appraisal--Northern Forest Fire Laboratory (NFFL) and National Fire-Danger Rating (NFDR) models. The NFFL models (Albini 1976) are also used for forecasting behavior of wildfire. Generally, the slash fuel models reflect an average of typical fuel conditions in Douglas-fir and ponderosa pine slash. The NFDR models (Deeming et al. 1977) differ from the NFFL series mainly in that a greater proportion of 1-hour timelag fuels are present relative to 10- and 100-hour fuels (1/4 inch to 3 inches). Packing ratios are similar, but NFFL models have more nearly optimum packing. Because of these differences, predictions for spread and intensity of fire for fuels with properties of the NFDR slash models will be slightly greater at low windspeeds--and much greater at high windspeeds--than fuels with the physical properties of NFFL slash models.

A choice between using the NFFL or NFDR series of models to represent the fuel bed in a photo from Maxwell and Ward (1976) was based on the proportion of fine fuels present and on the believability of the output on fire behavior. Residues from second-growth timber and red slash, because of a greater amount of 1-hour fuel loading, are better represented by NFDR models. Old-growth or overwintered slash has characteristics similar to NFFL models.

Rothermel's (1972) fire spread model is the basis for estimates of fire behavior. The algorithm used to estimate flame lengths for photographs judged similar to NFDR fuel models is the same used in the NFDR system. The fire spread model, however, depends on a continuous and homogeneous fuel bed, and adjustments are needed if those conditions do not prevail. Several fuel beds depicted in the

between fuel beds in a manner consistent with, but more precisely than, stylized fuel models. The user should not expect predicted values to be exact estimates of fire behavior on an actual fire on a specific unit. Deviations from one-half to two times the predicted values can be expected. Even values one-fourth to four times the actual value may occur. Deviations are also possible if the fuel inventory is inaccurate or if the character of the fuel bed is substantially different from the stylized fuel model.

Spread of fire is amplified by wind and slope. Effective wind (Albini 1976) is the windspeed that alone would produce the same amplification as the combined effects of wind and slope. The tables show effective wind at midflame height. Figure 1 can be used to determine effective midflame windspeed.

Fuel moisture content is calculated by combining the three fine fuel classes so that:

$$\text{Moisture content} = 0.76 \times (\text{1-hour timelag moisture}) + 0.18 \times (\text{10-hour timelag moisture}) + 0.06 \times (\text{100-hour timelag moisture}).$$

Fire perimeter, area, and resistance to control are other parameters useful for fire planning. Formula and graphic aids (Fire Behavior Officer's Field Reference[1]) for determining perimeter and area are presented in appendix 1. Fuel resistance to control rating, slope, and flame length adjustment factors,

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[1]National Interagency Fire Training Center, Marana, Arizona, 1978.

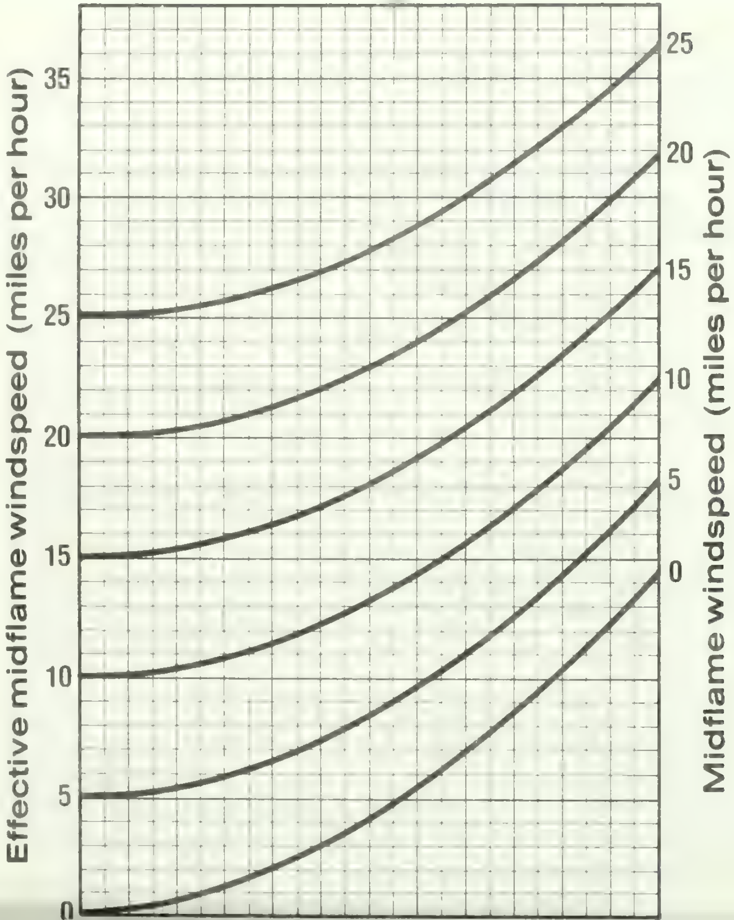

Figure 1.--Chart for determining effective windspeed from midflame windspeed and ground slope in direction of wind.

constructed by one person are presented in appendix 2.

For the approximate potential fire behavior and resistance of fuel to control for a particular area and given weather conditions, determine the following:

1. Which photo nearly matches, or which photos bracket, the area.
2. Rate of spread of fire and flame length (tables 1-42).
3. Perimeter and area of fire (from graphs and formulas in appendix 1).
4. Resistance of fuel to control (from tables in appendix 2).

For example, if the area was represented by photo 2-DF-4-CC in Maxwell and Ward (1976) and there was a 5-mi/h wind at midflame height, a fine fuel moisture of 4 percent, and the area was on a 20-percent slope, the following conditions would exist:

Effective midflame wind (miles per hour)--6
Rate of spread (chains per hour)--7
Flame length (feet)--4
Perimeter growth at 1 hour (chains)--20.5
Area at 1 hour (acres)--2.6
Resistance to suppression (chains/person-hour)--1.7

If the area was bracketed by two photos, interpolate by using the respective tables.

Literature Cited

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Douglas-fir--Hemlock

Size Class 4

Clearcut

Tables 1 Through 10

(Corresponds to Photo Series 1-DF-4-CC to 10-DF-4-CC in Maxwell and Ward 1976)

TABLE 1--FIRE BEHAVIOR AND CONTROL INFORMATION FOR PHOTO 1-DF-4-CC

FUEL MOISTURE	RATE OF SPREAD: EFFECTIVE MIDFLAME WIND (MI/H)									FLAME LENGTH: EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

TABLE 2 FIRE BEHAVIOR AND
(FIRE BEHAVIOR INFORMATION SCALED FROM NFFL MODELS)

FUEL MOISTURE	RATE OF SPREAD: EFFECTIVE MIDFLAME WIND (MI/H) 0	2	4	6	8	10	12	14	16	FLAME LENGTH: EFFECTIVE MIDFLAME WIND (MI/H) 0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	1	3	5	8	11	15	18	23	32	1	2	3	4	5	5	6	6	7
3	1	2	5	7	10	13	15	20	27	1	2	3	4	4	5	5	6	7
4	0	2	4	6	9	11	14	18	24	1	2	3	3	4	4	5	5	6
5	0	2	4	6	8	10	12	16	22	1	2	3	3	4	4	4	5	6
6	0	2	4	5	7	10	12	15	21	1	2	2	3	3	4	4	5	5
7	0	2	3	5	7	9	11	14	20	1	2	2	3	3	4	4	5	5
8	0	2	3	5	7	9	11	14	19	1	2	2	3	3	4	4	4	5
9	0	2	3	5	6	8	10	13	18	1	2	2	3	3	3	4	4	5
10	0	1	3	4	6	7	9	12	16	1	1	2	2	3	3	3	4	5
11	0	1	2	4	5	6	8	10	14	1	1	2	2	3	3	3	3	4
12	0	1	2	3	4	5	6	8	11	1	1	1	2	2	2	3	3	3
13	0	1	1	2	3	3	4	5	7	0	1	1	1	1	2	2	2	2
14	0	0	0	1	1	1	1	2	2	0	0	0	0	0	1	1	1	1

TABLE 3--FIRE BEHAVIOR AND CONTROL INFORMATION FOR PHOTO 3-DF-4-CC

FUEL MOISTURE	RATE OF SPREAD: EFFECTIVE MIDFLAME WIND (MI/H)									FLAME LENGTH: EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

(FIRE BEHAVIOR INFORMATION SCALED FROM NFFL MODELS)

FUEL MOISTURE	RATE OF SPREAD									FLAME LENGTH								
	EFFECTIVE MIDFLAME WIND (MI/H)									EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	1	4	9	12	16	20	25	32	44	2	4	5	6	7	8	8	9	11
3	1	3	7	10	14	17	21	27	38	2	3	4	5	6	7	7	8	10
4	1	3	6	9	12	15	19	24	33	1	3	4	5	6	6	7	8	9
5	1	3	5	8	11	14	17	22	30	1	3	4	4	5	6	6	7	8
6	1	3	5	8	10	13	16	21	28	1	3	4	4	5	6	6	7	8
7	1	2	5	7	10	12	15	19	27	1	3	3	4	5	5	6	7	8
8	1	2	4	7	9	12	14	19	26	1	2	3	4	5	5	6	6	7
9	0	2	4	6	9	11	14	18	24	1	2	3	4	4	5	6	6	7
10	0	2	4	6	8	11	13	16	23	1	2	3	4	4	5	5	6	7
11	0	2	4	6	8	10	12	15	21	1	2	3	3	4	4	5	5	6
12	0	2	3	5	7	9	10	13	16	1	2	3	3	4	4	4	5	6
13	0	1	3	4	5	7	8	11	15	1	2	2	3	3	3	4	4	5
14	0	1	2	3	4	5	6	7	10	1	1	2	2	2	2	3	3	3
15	0	0	1	1	2	2	3	3	5	0	1	1	1	1	1	1	1	2

TABLE 5--FIRE BEHAVIOR AND CONTROL INFORMATION FOR PHOTO 5-DF-4-CC
(FIRE BEHAVIOR INFORMATION SCALED FROM NFFL MODELS)

FUEL MOISTURE	RATE OF SPREAD									FLAME LENGTH								
	EFFECTIVE MIDFLAME WIND (MI/H)									EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	1	3	5	8	10	13	16	21	29	1	2	3	4	4	5	5	6	7
3	0	2	4	7	9	11	14	18	25	1	2	3	3	4	4	5	5	6
4	0	2	4	6	8	10	12	16	22	1	2	2	3	3	4	4	5	5
5	0	2	3	5	7	9	11	15	20	1	2	2	3	3	4	4	4	5
6	0	2	3	5	7	9	11	14	19	1	2	2	3	3	3	4	4	5
7	0	2	3	5	7	8	10	13	18	1	2	2	3	3	3	4	4	5
8	0	1	3	5	6	8	10	12	17	1	1	2	2	3	3	4	4	5
9	0	1	3	4	6	7	9	12	16	1	1	2	2	3	3	3	4	4
10	0	1	2	4	5	7	8	10	14	1	1	2	2	3	3	3	3	4
11	0	1	2	3	4	6	7	9	12	1	1	2	2	2	2	3	3	4
12	0	1	2	2	3	4	5	7	9	0	1	1	1	2	2	2	2	3
13	0	0	1	1	2	3	3	4	6	0	1	1	1	1	1	1	1	2
14	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0

FUEL MOISTURE	RATE OF SPREAD — EFFECTIVE MIDFLAME WIND (MI/H)									FLAME LENGTH — EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

TABLE 7--FIRE BEHAVIOR AND CONTROL INFORMATION FOR PHOTO 7-DF-4-CC
(FIRE BEHAVIOR INFORMATION SCALED FROM NFFL MODELS)

FUEL MOISTURE	RATE OF SPREAD: EFFECTIVE MIDFLAME WIND (MI/H)									FLAME LENGTH: EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	1	4	8	12	15	21	25	33	45	2	4	5	6	7	8	9	10	11
3	1	3	7	10	14	18	22	28	39	2	3	4	5	6	7	8	9	10
4	1	3	6	9	12	16	19	25	34	2	3	4	5	6	6	7	8	9
5	1	3	5	8	11	14	18	23	31	1	3	4	5	5	6	7	7	9
6	1	3	5	8	11	13	16	21	29	1	3	4	4	5	6	6	7	8
7	1	2	5	7	10	13	16	20	27	1	3	4	4	5	5	6	7	8
8	1	2	5	7	9	12	15	19	26	1	3	3	4	5	5	6	7	8
9	1	2	4	7	9	12	14	18	25	1	2	3	4	5	5	6	6	7
10	0	2	4	6	8	11	13	17	23	1	2	3	4	4	5	5	6	7
11	0	2	4	6	8	10	12	15	21	1	2	3	4	4	5	5	6	7
12	0	2	3	5	7	9	11	14	19	1	2	3	3	4	4	5	5	6
13	0	1	3	4	6	7	9	11	15	1	2	2	3	3	3	4	4	5
14	0	1	2	3	4	5	6	8	11	1	1	2	2	2	3	3	3	4
15	0	0	1	1	2	2	3	4	5	0	1	1	1	1	1	1	2	2

AND CONTROL INFORMATION FOR PHOTO 8-DF-4-CC
(FIRE BEHAVIOR INFORMATION SCALED FROM NFFL MODELS)

FUEL MOISTURE	RATE OF SPREAD									FLAME LENGTH								
	EFFECTIVE MIDFLAME WIND (MI/H)									EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	1	3	7	10	14	17	21	27	38	2	3	4	5	6	6	7	8	9
3	1	3	6	9	12	15	18	23	32	1	3	4	4	5	6	6	7	8
4	1	3	5	8	10	13	16	21	29	1	2	3	4	5	5	6	6	7
5	1	2	5	7	9	12	15	19	26	1	2	3	4	4	5	5	6	7
6	0	2	4	6	9	11	14	18	24	1	2	3	4	4	5	5	6	7
7	0	2	4	6	8	11	13	17	23	1	2	3	3	4	4	5	5	6
8	0	2	4	6	8	10	12	16	22	1	2	3	3	4	4	5	5	6
9	0	2	4	6	8	10	12	15	21	1	2	3	3	4	4	5	5	6
10	0	2	3	5	7	9	11	14	19	1	2	3	3	4	4	4	5	6
11	0	2	3	5	6	8	10	12	17	1	2	2	3	3	4	4	4	5
12	0	1	2	4	5	7	8	10	14	1	1	2	2	3	3	3	4	4
13	0	1	2	3	4	5	6	8	11	1	1	1	2	2	2	3	3	3
14	0	1	1	2	2	3	3	4	6	0	1	1	1	1	1	1	2	2

TABLE 9--FIRE BEHAVIOR AND CONTROL INFORMATION FOR PHOTO 9-DF-4-CC
(FIRE BEHAVIOR INFORMATION SCALED FROM NFFL MODELS)

FUEL MOISTURE	RATE OF SPREAD: EFFECTIVE MIDFLAME WIND (MI/H)									FLAME LENGTH: EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	1	4	7	11	15	19	24	30	42	2	3	5	6	7	7	8	9	10
3	1	3	6	10	13	17	20	26	36	2	3	4	5	6	6	7	8	9
4	1	3	6	9	12	15	18	23	32	1	3	4	5	5	6	6	7	8
5	1	3	5	8	11	13	16	21	29	1	3	4	4	5	5	6	7	8
6	1	2	5	7	10	13	15	20	27	1	2	3	4	5	5	6	6	7
7	1	2	4	7	9	12	15	19	26	1	2	3	4	5	5	6	6	7
8	0	2	4	7	9	11	14	18	24	1	2	3	4	4	5	5	6	7
9	0	2	4	6	8	11	13	17	23	1	2	3	4	4	5	5	6	7
10	0	2	4	6	8	10	12	16	22	1	2	3	4	4	5	5	6	6
11	0	2	3	5	7	9	11	14	20	1	2	3	3	4	4	5	5	6
12	0	2	3	4	6	8	10	12	17	1	2	2	3	3	4	4	5	5
13	0	1	2	4	5	6	8	10	13	1	1	2	2	3	3	3	4	4
14	0	1	2	2	3	4	5	6	9	0	1	1	2	2	2	2	3	3
15	0	0	1	1	1	1	2	2	3	0	0	0	1	1	1	1	1	1

FUEL MOISTURE	RATE OF SPREAD: EFFECTIVE MIDFLAME WIND (MI/H) 0	2	4	6	8	10	12	14	16	FLAME LENGTH: EFFECTIVE MIDFLAME WIND (MI/H) 0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	1	4	7	11	15	19	23	29	40	2	3	4	5	6	7	8	9	10
3	1	3	5	9	12	16	19	25	35	1	3	4	5	5	6	7	8	9
4	1	3	5	8	11	14	17	22	31	1	3	4	4	5	6	6	7	8
5	1	2	5	7	10	13	16	20	28	1	2	3	4	5	5	6	6	7
6	1	2	5	7	9	12	15	19	26	1	2	3	4	4	5	5	6	7
7	0	2	4	7	9	11	14	16	25	1	2	3	4	4	5	5	6	7
8	0	2	4	6	9	11	13	17	24	1	2	3	4	4	5	5	6	7
9	0	2	4	6	8	10	13	16	22	1	2	3	4	4	5	5	6	6
10	0	2	4	5	7	10	12	15	21	1	2	3	3	4	4	5	5	6
11	0	2	3	5	7	9	11	13	19	1	2	3	3	4	4	4	5	6
12	0	1	3	4	6	7	9	11	16	1	2	2	3	3	3	4	4	5
13	0	1	2	3	4	6	7	9	12	1	1	2	2	2	3	3	3	4
14	0	1	1	2	3	3	4	5	7	0	1	1	1	2	2	2	2	3
15	0	0	0	0	1	1	1	1	2	0	0	0	0	0	0	0	1	1

Douglas-fir--Hemlock

Size Class 4

Partial Cut

Tables 11 Through 19

(Corresponds to Photo Series 1-DF-4-PC to 9-DF-4-PC in Maxwell and Ward 1976)

TABLE 11 FIRE BEHAVIOR AND CONTROL INFORMATION FOR PHOTO 1-DF-4-PC

FUEL MOISTURE	RATE OF SPREAD									FLAME LENGTH								
	EFFECTIVE MIDFLAME WIND (MI/H)									EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

TABLE 12--FIRE BEHAVIOR AND CONTROL INFORMATION FOR PHOTO 2-OF-4-PC
(FIRE BEHAVIOR INFORMATION SCALE, FROM NFDR MODELS)

FUEL MOISTURE	RATE OF SPREAD: EFFECTIVE MIDFLAME WIND (MI/H) 0	2	4	6	8	10	12	14	16	FLAME LENGTH: EFFECTIVE MIDFLAME WIND (MI/H) 0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	1	4	8	13	18	24	29	39	55	2	4	5	7	9	10	11	12	14
3	1	3	7	11	16	21	26	34	49	2	4	5	7	8	9	10	11	13
4	1	3	6	10	14	19	23	30	43	2	4	5	6	7	8	9	10	12
5	1	3	6	9	13	17	21	27	39	2	3	5	6	7	7	8	9	11
6	1	3	5	8	12	15	19	25	36	2	3	4	5	6	7	8	9	10
7	1	2	5	8	11	14	18	23	33	1	3	4	5	6	6	7	8	9
8	1	2	5	7	10	13	17	22	31	1	3	4	4	5	5	7	7	9
9	1	2	4	7	10	13	16	21	29	1	2	3	4	5	5	6	7	8
10	0	2	4	7	9	12	15	20	28	1	2	3	4	5	5	6	6	8
11	0	2	4	6	9	12	14	19	27	1	2	3	4	4	5	5	6	7
12	0	2	4	6	8	11	14	18	26	1	2	3	3	4	4	5	6	7
13	0	2	4	6	8	11	13	17	25	1	2	3	3	4	4	5	5	6
14	0	2	4	6	8	10	13	17	24	1	2	2	3	3	4	4	5	6
15	0	2	3	5	8	10	12	16	23	1	2	2	3	3	4	4	5	5
16	0	2	3	5	7	9	12	15	22	1	1	2	3	3	3	4	4	5
17	0	1	3	5	7	9	11	14	20	1	1	2	2	3	3	3	4	4
18	0	1	3	4	6	8	10	13	19	1	1	2	2	2	3	3	3	4
19	0	1	3	4	6	7	9	12	17	1	1	1	2	2	2	3	3	4
20	0	1	2	4	5	7	8	11	15	0	1	1	2	2	2	2	3	3
21	0	1	2	3	4	6	7	9	13	0	1	1	1	2	2	2	2	3
22	0	1	2	2	3	4	5	7	10	0	1	1	1	1	1	1	2	2
23	0	1	1	2	2	3	4	5	7	0	0	1	1	1	1	1	1	1

FUEL MOISTURE	RATE OF SPREAD — EFFECTIVE MIDFLAME WIND (MI/H)									FLAME LENGTH — EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

TABLE 14--FIRE BEHAVIOR AND CONTROL INFORMATION FOR PHOTO 4-DF-4-PC
(FIRE BEHAVIOR INFORMATION SCALED FROM NFFL MODELS)

FUEL MOISTURE	RATE OF SPREAD									FLAME LENGTH								
	EFFECTIVE MIDFLAME WIND (MI/H)									EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	1	3	6	9	12	16	19	25	34	1	3	4	4	5	6	6	7	8
3	1	3	5	8	11	14	17	21	30	1	2	3	4	5	5	6	6	7
4	1	2	5	7	9	12	15	19	26	1	2	3	4	4	5	5	6	7
5	0	2	4	6	9	11	13	17	24	1	2	3	3	4	4	5	5	6
6	0	2	4	6	8	10	13	16	22	1	2	3	3	4	4	5	5	6
7	0	2	4	6	9	10	12	15	21	1	2	3	3	4	4	4	5	6
8	0	2	3	5	7	9	11	15	20	1	2	2	3	3	4	4	5	6
9	0	2	3	5	7	9	11	14	19	1	2	2	3	3	4	4	5	5
10	0	2	3	5	6	8	10	13	17	1	2	2	3	3	4	4	4	5
11	0	1	3	4	6	7	9	11	15	1	1	2	2	3	3	3	4	4
12	0	1	2	3	4	6	7	9	12	1	1	2	2	2	3	3	3	4
13	0	1	1	2	3	4	5	6	9	0	1	1	1	2	2	2	2	3
14	0	0	1	1	1	2	2	3	4	0	0	1	1	1	1	1	1	1

FUEL MOISTURE	RATE OF SPREAD									FLAME LENGTH								
	EFFECTIVE MIDFLAME WIND (MI/H)									EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

TABLE 16--FIRE BEHAVIOR AND CONTROL INFORMATION FOR PHOTO 5-OF-4-PC
(FIRE BEHAVIOR INFORMATION SCALED FROM NFDR MODELS)

FUEL MOISTURE	RATE OF SPREAD									FLAME LENGTH								
	EFFECTIVE MIDFLAME WIND (MI/H)									EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	1	5	11	17	24	31	38	53	72	3	6	9	11	13	14	16	18	21
3	1	5	9	15	21	27	34	44	62	3	6	8	10	11	13	14	16	19
4	1	4	8	13	19	24	30	[illegible]	56	3	5	7	9	10	12	13	15	17
5	1	4	8	12	17	22	27	37	51	3	5	7	9	10	11	12	14	16
6	1	3	7	11	15	20	25	33	47	2	4	6	8	9	10	11	12	15
7	1	3	6	10	14	19	23	33	43	2	4	6	7	8	9	10	12	14
8	1	3	6	9	13	17	22	29	40	2	4	5	6	8	9	9	11	13
9	1	3	6	9	13	16	20	27	38	2	4	5	6	7	8	9	10	12
10	1	3	5	9	12	16	19	26	36	2	3	5	6	7	7	8	9	11
11	1	3	5	8	11	15	19	24	35	2	3	4	5	6	7	8	9	10
12	1	2	5	8	11	14	16	24	34	2	3	4	5	6	7	7	8	10
13	1	2	5	8	11	14	17	23	32	1	3	4	5	5	6	7	8	9
14	1	2	5	7	10	13	17	22	31	1	2	3	4	5	6	6	7	8
15	1	2	4	7	10	13	16	21	30	1	2	3	4	5	5	6	7	8
16	1	2	4	7	9	12	15	20	28	1	2	3	4	4	5	5	6	7
17	0	2	4	6	9	11	14	19	27	1	2	3	3	4	4	5	5	6
18	0	2	4	6	8	11	13	17	25	1	2	2	3	3	4	4	5	6
19	0	2	3	5	7	10	12	16	22	1	2	2	3	3	3	4	4	5
20	0	1	3	5	7	8	11	14	20	1	1	2	2	3	3	3	4	4
21	0	1	2	4	6	7	9	12	17	1	1	2	2	2	2	3	3	4
22	0	1	2	3	4	6	7	9	13	0	1	1	1	2	2	2	2	3
23	0	1	1	2	3	4	5	7	9	0	1	1	1	1	1	2	2	2
24	0	0	1	1	2	2	3	3	5	0	0	0	1	1	1	[illegible]	[illegible]	[illegible]

FUEL MOISTURE	RATE OF SPREAD: EFFECTIVE MIDFLAME WIND (MI/H)									FLAME LENGTH: EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	1	3	7	10	14	18	22	28	39	2	3	4	5	5	7	7	8	9
3	1	3	6	9	12	15	19	24	33	1	3	4	5	5	6	6	7	8
4	1	3	5	8	11	14	17	21	29	1	3	3	4	5	5	6	7	8
5	1	2	5	7	10	12	15	19	27	1	2	3	4	4	5	5	6	7
6	0	2	4	7	9	12	14	18	25	1	2	3	4	4	5	5	6	7
7	0	2	4	6	9	11	13	17	24	1	2	3	4	4	5	5	6	7
8	0	2	4	6	8	10	13	16	23	1	2	3	3	4	4	5	6	6
9	0	2	4	6	8	10	12	16	21	1	2	3	3	4	4	5	5	6
10	0	2	3	5	7	9	11	14	20	1	2	3	3	4	4	4	5	6
11	0	2	3	5	6	8	10	13	18	1	2	2	3	3	4	4	5	5
12	0	1	3	4	5	7	8	11	15	1	2	2	2	3	3	4	4	5
13	0	1	2	3	4	5	6	8	11	1	1	2	2	2	3	3	3	4
14	0	1	1	2	2	3	4	5	6	0	1	1	1	1	2	2	2	2
15	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0

TABLE 18--FIRE BEHAVIOR AND CONTROL INFORMATION FOR PHOTO 8-DF-4-PC
(FIRE BEHAVIOR INFORMATION SCALED FROM NFFL MODELS)

FUEL MOISTURE	RATE OF SPREAD									FLAME LENGTH								
	EFFECTIVE MIDFLAME WIND (MI/H)									EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	1	3	7	10	14	17	21	27	36	2	3	4	5	5	6	7	8	9
3	1	3	6	9	12	15	18	23	32	1	3	4	4	5	6	6	7	8
4	1	3	5	8	10	13	16	21	29	1	2	3	4	5	5	6	6	7
5	1	2	5	7	9	12	15	19	26	1	2	3	4	4	5	5	6	7
6	0	2	4	6	9	11	14	18	24	1	2	3	4	4	5	5	6	7
7	0	2	4	6	8	11	13	17	23	1	2	3	3	4	4	5	5	6
8	0	2	4	6	8	10	12	16	22	1	2	3	3	4	4	5	5	6
9	0	2	4	6	8	10	12	15	21	1	2	3	3	4	4	5	5	6
10	0	2	3	5	7	9	11	14	19	1	2	3	3	4	4	4	5	6
11	0	2	3	5	6	8	10	12	17	1	2	2	3	3	4	4	4	5
12	0	1	2	4	5	7	8	10	14	1	1	2	2	3	3	3	4	4
13	0	1	2	3	4	5	6	8	11	1	1	2	2	2	2	3	3	3
14	0	1	1	2	2	3	3	4	6	0	1	1	1	1	1	2	2	2

BEHAVIOR INFORMATION SCALED FROM NFFL MODELS)

FUEL MOISTURE	RATE OF SPREAD: EFFECTIVE MIDFLAME WIND (MI/H)									FLAME LENGTH: EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	1	2	5	7	10	13	16	20	28	1	2	3	3	4	5	5	6	6
3	0	2	4	6	9	11	14	18	24	1	2	3	3	4	4	4	5	6
4	0	2	4	6	8	10	12	16	22	1	2	2	3	3	4	4	4	5
5	0	2	3	5	7	9	11	14	20	1	2	2	3	3	3	4	4	5
6	0	2	3	5	7	8	10	13	19	1	2	2	3	3	3	4	4	5
7	0	2	3	5	6	8	10	13	18	1	1	2	2	3	3	3	4	5
8	0	1	3	4	6	8	9	12	17	1	1	2	2	3	3	3	4	4
9	0	1	3	4	6	7	9	11	16	1	1	2	2	3	3	3	4	4
10	0	1	2	4	5	6	8	10	14	1	1	2	2	2	3	3	3	4
11	0	1	2	3	4	5	7	9	12	1	1	1	2	2	2	3	3	3
12	0	1	2	2	3	4	5	6	9	0	1	1	1	2	2	2	2	3
13	0	0	1	1	2	2	3	4	5	0	1	1	1	1	1	1	1	2
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Douglas-fir--Hemlock

Size Class 3

Partial Cut

Tables 20 Through 25

(Corresponds to Photo Series 1-DF-3-PC to 6-DF-3-PC in Maxwell and Ward 1976)

INFORMATION SCALED FROM NFFL MODELS)

FUEL MOISTURE	RATE OF SPREAD									FLAME LENGTH								
	EFFECTIVE MIDFLAME WIND (MI/H)									EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	0	2	3	5	7	9	11	15	20	1	1	2	2	3	3	3	4	4
3	0	1	3	4	6	8	10	12	17	1	1	2	2	2	3	3	3	4
4	0	1	3	4	5	7	9	11	15	1	1	2	2	2	2	3	3	3
5	0	1	2	4	5	6	8	10	14	0	1	1	2	2	2	2	3	3
6	0	1	2	3	5	6	7	10	13	0	1	1	2	2	2	2	3	3
7	0	1	2	3	5	6	7	9	13	0	1	1	2	2	2	2	3	3
8	0	1	2	3	4	5	7	9	12	0	1	1	2	2	2	2	3	3
9	0	1	2	3	4	5	6	8	11	0	1	1	1	2	2	2	2	3
10	0	1	2	2	3	4	5	7	10	0	1	1	1	2	2	2	2	2
11	0	1	1	2	3	3	4	6	8	0	1	1	1	1	1	2	2	2
12	0	0	1	1	2	2	3	4	5	0	0	1	1	1	1	1	1	1
13	0	0	0	0	1	1	1	1	2	0	0	0	0	0	0	0	0	1

TABLE 21--FIRE BEHAVIOR AND CONTROL INFORMATION FOR PHOTO 2-DF-3-PC (RATE OF SPREAD ESTIMATES ARE ONE-HALF OF NFFL CONTINUOUS SLASH MODEL)

FUEL MOISTURE	RATE OF SPREAD									FLAME LENGTH								
	EFFECTIVE MIDFLAME WIND (MI/H)									EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	0	1	2	3	4	5	6	8	12	1	1	2	2	2	2	3	3	4
3	0	1	2	3	4	5	6	7	10	0	1	1	2	2	2	2	3	3
4	0	1	1	2	3	4	5	6	9	0	1	1	2	2	2	2	2	3
5	0	1	1	2	3	4	5	6	8	0	1	1	1	2	2	2	2	3
6	0	1	1	2	3	3	4	5	8	0	1	1	1	2	2	2	2	3
7	0	1	1	2	3	3	4	5	7	0	1	1	1	2	2	2	2	3
8	0	1	1	2	2	3	4	5	7	0	1	1	1	2	2	2	2	2
9	0	1	1	2	2	3	4	5	6	0	1	1	1	1	2	2	2	2
10	0	0	1	1	2	3	3	4	6	0	1	1	1	1	1	2	2	2
11	0	0	1	1	2	2	3	3	5	0	1	1	1	1	1	1	1	2
12	0	0	1	1	1	1	2	2	3	0	0	1	1	1	1	1	1	1
13	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1

(FIRE BEHAVIOR INFORMATION SCALED FROM NFFL MODELS)

FUEL MOISTURE	RATE OF SPREAD: EFFECTIVE MIDFLAME WIND (MI/H)									FLAME LENGTH: EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	0	2	4	6	8	11	13	17	24	1	2	2	3	3	4	4	4	5
3	0	2	3	5	7	9	11	15	20	1	1	2	2	3	3	4	4	5
4	0	2	3	5	6	8	10	13	18	1	1	2	2	3	3	3	4	4
5	0	1	3	4	6	8	9	12	17	1	1	2	2	2	3	3	3	4
6	0	1	3	4	6	7	9	11	16	1	1	2	2	2	3	3	3	4
7	0	1	3	4	5	7	8	11	15	1	1	2	2	2	3	3	3	4
8	0	1	2	4	5	6	8	10	14	1	1	2	2	2	2	3	3	4
9	0	1	2	3	5	6	7	9	13	1	1	1	2	2	2	3	3	3
10	0	1	2	3	4	5	6	8	11	0	1	1	2	2	2	2	3	3
11	0	1	2	2	3	4	5	7	9	0	1	1	1	2	2	2	2	3
12	0	1	1	2	2	3	4	5	7	0	1	1	1	1	1	1	2	2
13	0	0	0	1	1	1	2	2	3	0	0	0	0	1	1	1	1	1

TABLE 23--FIRE BEHAVIOR AND CONTROL INFORMATION FOR PHOTO 4-DF-3-PC (RATE OF SPREAD ESTIMATES ARE ONE-HALF OF NFFL CONTINUOUS SLASH MODEL)

FUEL MOISTURE	RATE OF SPREAD									FLAME LENGTH								
	EFFECTIVE MIDFLAME WIND (MI/H)									EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	0	1	3	4	5	7	9	11	15	1	2	2	3	3	3	4	4	5
3	0	1	2	3	5	6	7	9	13	1	1	2	2	3	3	3	4	4
4	0	1	2	3	4	5	6	8	12	1	1	2	2	3	3	3	3	4
5	0	1	2	3	4	5	6	6	11	1	1	2	2	2	3	3	3	4
6	0	1	2	3	4	5	6	7	10	1	1	2	2	2	3	3	3	4
7	0	1	2	2	3	4	5	7	9	1	1	2	2	2	2	3	3	4
8	0	1	2	2	3	4	5	6	9	1	1	2	2	2	2	3	3	3
9	0	1	1	2	3	4	5	6	8	1	1	1	2	2	2	2	3	3
10	0	1	1	2	3	3	4	5	8	0	1	1	2	2	2	2	3	3
11	0	1	1	2	2	3	4	5	6	0	1	1	1	2	2	2	2	3
12	0	0	1	1	2	2	3	4	5	0	1	1	1	1	1	2	2	2
13	0	0	1	1	1	1	2	2	3	0	0	1	1	1	1	1	1	1
14	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0

INFORMATION SCALED FROM NFFL MODELS)

FUEL MOISTURE	RATE OF SPREAD — EFFECTIVE MIDFLAME WIND (MI/H)									FLAME LENGTH — EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	1	5	9	13	[illegible]	23	28	34	50	2	4	6	7	8	9	10	11	13
3	1	4	[illegible]	12	16	20	24	31	43	2	4	5	6	7	8	9	10	11
4	1	3	7	10	14	18	22	28	38	2	3	5	6	7	7	8	9	10
5	1	3	6	9	13	16	20	25	35	2	3	4	5	6	7	7	8	10
6	1	3	6	9	12	15	18	23	32	2	3	4	5	6	6	7	8	9
7	1	3	5	8	11	14	17	22	30	2	3	4	5	6	6	7	8	9
8	1	3	5	8	11	13	16	21	29	1	3	4	5	5	6	7	7	9
9	1	3	5	7	10	13	16	20	28	1	3	4	5	5	6	6	7	8
10	1	2	5	7	10	12	15	19	26	1	3	4	4	5	6	6	7	8
11	1	2	4	6	9	11	14	18	24	1	3	3	4	5	5	6	7	8
12	0	2	4	6	8	10	12	16	22	1	2	3	4	4	5	5	6	7
13	0	2	3	5	7	9	11	14	19	1	2	3	3	4	4	5	5	6
14	0	1	3	4	5	7	8	11	15	1	2	2	3	3	3	4	4	5
15	0	1	2	3	3	4	5	7	9	1	1	2	2	2	2	3	3	3
16	0	0	1	1	1	2	2	2	3	0	0	1	1	1	1	1	1	1

TABLE 25--FIRE BEHAVIOR AND CONTROL INFORMATION FOR PHOTO 6-DF-3-PC

FUEL MOISTURE	RATE OF SPREAD									FLAME LENGTH								
	EFFECTIVE MIDFLAME WIND (MI/H)									EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Douglas-fir--Hemlock

Size Class 1

Precommercial Thinning

Tables 26 Through 29

(Corresponds to Photo Series 1-DF-1-TH to 4-DF-1-TH in Maxwell and Ward 1976)

TABLE 26--FIRE BEHAVIOR AND CONTROL INFORMATION FOR PHOTO 1-DF-1-TH
(FIRE BEHAVIOR INFORMATION SCALED FROM NFFL MODELS)

FUEL MOISTURE	RATE OF SPREAD									FLAME LENGTH								
	EFFECTIVE MIDFLAME WIND (MI/H)									EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	0	1	1	2	3	4	5	6	9	0	0	1	1	1	1	1	1	2
3	0	1	1	2	3	3	4	5	7	0	0	1	1	1	1	1	1	1
4	0	1	1	2	2	3	4	5	7	0	0	1	1	1	1	1	1	1
5	0	0	1	2	2	3	3	4	6	0	0	0	1	1	1	1	1	1
6	0	0	1	1	2	3	3	4	6	0	0	0	1	1	1	1	1	1
7	0	0	1	1	2	2	3	4	5	0	0	0	1	1	1	1	1	1
8	0	0	1	1	2	2	[illegible]	3	5	0	0	0	1	1	1	1	1	1
9	0	0	1	1	2	2	3	3	5	0	0	0	0	1	1	1	1	1
10	0	0	1	1	1	2	2	3	4	0	0	0	0	0	1	1	1	1
11	0	0	0	1	1	1	2	2	3	0	0	0	0	0	0	0	1	1
12	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0

FUEL MOISTURE	RATE OF SPREAD									FLAME LENGTH								
	EFFECTIVE MIDFLAME WIND (MI/H)									EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	0	2	4	6	8	11	14	18	26	1	2	2	3	3	4	4	5	5
3	0	2	3	5	7	10	12	16	23	1	2	2	3	3	3	4	4	5
4	0	1	3	5	7	9	11	14	20	1	1	2	2	3	3	4	4	5
5	0	1	3	4	6	8	10	13	18	1	1	2	2	3	3	3	4	4
6	0	1	2	4	6	7	9	12	17	1	1	2	2	2	3	3	3	4
7	0	1	2	4	5	7	8	11	16	1	1	2	2	2	2	3	3	4
8	0	1	2	3	5	6	8	10	15	0	1	1	2	2	2	3	3	3
9	0	1	2	3	5	6	7	10	14	0	1	1	2	2	2	2	3	3
10	0	1	2	3	4	6	7	9	13	0	1	1	2	2	2	2	3	3
11	0	1	2	3	4	5	7	9	13	0	1	1	1	2	2	2	2	3
12	0	1	2	3	4	5	6	9	12	0	1	1	1	2	2	2	2	3
13	0	1	2	3	4	5	6	8	12	0	1	1	1	1	2	2	2	2
14	0	1	2	3	4	5	6	8	11	0	1	1	1	1	2	2	2	2
15	0	1	2	3	4	5	6	8	11	0	1	1	1	1	1	2	2	2
16	0	1	1	2	3	4	5	7	10	0	1	1	1	1	1	1	2	2
17	0	1	1	2	3	4	5	7	10	0	1	1	1	1	1	1	1	2
18	0	1	1	2	3	4	5	6	9	0	0	1	1	1	1	1	1	2
19	0	1	1	2	3	3	4	6	8	0	0	1	1	1	1	1	1	1
20	0	0	1	2	2	3	4	5	7	0	0	0	1	1	1	1	1	1
21	0	0	1	1	2	3	3	4	6	0	0	0	1	1	1	1	1	1
22	0	0	1	1	2	2	3	3	5	0	0	0	0	0	1	1	1	1
23	0	0	0	1	1	1	2	2	3	0	0	0	0	0	0	0	0	1
24	0	0	0	0	1	1	1	1	2	0	0	0	0	0	0	0	0	0

TABLE 28--FIRE BEHAVIOR AND CONTROL INFORMATION FOR PHOTO 3-DF-1-TH
(FIRE BEHAVIOR INFORMATION SCALED FROM NFDR MODELS)

FUEL MOISTURE	RATE OF SPREAD: EFFECTIVE MIDFLAME WIND (MI/H)									FLAME LENGTH: EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	1	4	8	13	18	24	29	39	55	2	5	7	8	9	11	12	13	15
3	1	4	7	11	16	21	26	34	49	2	4	6	7	9	10	11	12	14
4	1	3	6	10	14	19	23	30	43	2	4	5	7	8	9	10	11	13
5	1	3	6	9	13	17	21	28	39	2	4	5	6	7	8	9	10	12
6	1	3	5	8	12	15	19	25	36	2	3	5	6	7	7	8	9	11
7	1	2	5	8	11	14	18	23	33	2	3	4	5	6	7	8	9	10
8	1	2	5	7	10	13	17	22	31	1	3	4	5	6	6	7	8	9
9	1	2	4	7	10	13	16	21	29	1	3	4	4	5	6	7	7	9
10	0	2	4	7	9	12	15	20	28	1	2	3	4	5	6	6	7	8
11	0	2	4	6	9	12	14	19	27	1	2	3	4	5	5	6	7	8
12	0	2	4	6	8	11	14	18	26	1	2	3	4	4	5	5	6	7
13	0	2	4	6	8	11	13	17	25	1	2	3	3	4	5	5	6	7
14	0	2	4	6	8	10	13	17	24	1	2	3	3	4	4	5	5	6
15	0	2	3	5	8	10	12	16	23	1	2	2	3	3	4	4	5	6
16	0	2	3	5	7	9	12	15	22	1	2	2	3	3	4	4	4	5
17	0	1	3	5	7	9	11	14	20	1	1	2	2	3	3	4	4	5
18	0	1	3	4	6	8	10	13	19	1	1	2	2	3	3	3	4	4
19	0	1	3	4	6	7	9	12	17	1	1	2	2	2	3	3	3	4
20	0	1	2	4	5	7	8	11	15	1	1	1	2	2	2	2	3	3
21	0	1	2	3	4	6	7	9	13	0	1	1	1	2	2	2	2	3
22	0	1	2	2	3	4	5	7	10	0	1	1	1	1	1	2	2	2
23	0	1	1	2	2	3	4	5	7	0	0	1	1	1	1	1	1	[illegible]

FUEL MOISTURE	RATE OF SPREAD									FLAME LENGTH								
	EFFECTIVE MIDFLAME WIND (MI/H)									EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	2	6	13	20	28	36	45	59	84	3	6	8	10	11	13	14	16	19
3	1	5	11	19	25	32	40	52	75	3	5	7	9	10	12	13	14	17
4	1	5	10	16	22	29	36	47	67	2	5	6	8	9	10	12	13	15
5	1	4	9	14	20	26	32	42	60	2	4	6	7	9	10	11	12	14
6	1	4	8	13	18	24	29	39	55	2	4	5	7	8	9	10	11	13
7	1	4	8	12	17	22	27	36	51	2	4	5	6	7	8	9	10	12
8	1	3	7	11	16	20	26	33	48	2	3	5	6	7	8	8	10	11
9	1	3	7	11	15	19	24	32	45	2	3	4	5	6	7	8	9	10
10	1	3	6	10	14	18	23	30	43	2	3	4	5	5	7	7	8	10
11	1	3	6	10	14	18	22	29	41	1	3	4	5	5	6	7	8	9
12	1	3	6	9	13	17	21	28	40	1	3	4	4	5	6	6	7	9
13	1	3	6	9	13	16	20	27	38	1	2	3	4	5	5	6	7	8
14	1	3	5	9	12	16	20	26	37	1	2	3	4	4	5	6	6	7
15	1	3	5	8	12	15	19	25	35	1	2	3	4	4	5	5	6	7
16	1	2	5	8	11	14	18	23	33	1	2	3	3	4	4	5	5	6
17	1	2	5	7	10	14	17	22	31	1	2	2	3	3	4	4	5	6
18	1	2	4	7	10	13	16	20	29	1	2	2	3	3	3	4	4	5
19	0	2	4	6	9	11	14	19	26	1	1	2	2	3	3	3	4	5
20	0	2	3	5	8	10	13	16	23	1	1	2	2	2	3	3	3	4
21	0	1	3	5	7	9	11	14	20	1	1	1	2	2	2	2	3	3
22	0	1	2	4	5	7	8	11	16	0	1	1	1	2	2	2	2	3
23	0	1	2	3	4	5	6	8	11	0	1	1	1	1	1	1	2	2
24	0	0	1	1	2	3	3	4	6	0	0	0	0	1	1	1	1	1

Douglas-fir--Hardwood

Size Class 4

Clearcut

Tables 30 Through 36

(Corresponds to Photo Series 1-DFHD-4-CC to 7-DFHD-4-CC in Maxwell and Ward 1976)

FUEL MOISTURE	RATE OF SPREAD									FLAME LENGTH								
	EFFECTIVE MIDFLAME WIND (MI/H)									EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

TABLE 31--FIRE BEHAVIOR AND CONTROL INFORMATION FOR PHOTO [illegible]-DFHD-4-CC (RATE OF SPREAD ESTIMATES ARE ONE-HALF OF NFFL CONTINUOUS SLASH MODEL)

FUEL MOISTURE	RATE OF SPREAD									FLAME LENGTH								
	EFFECTIVE MIDFLAME WIND (MI/H)									EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	0	1	2	4	5	6	8	10	14	1	1	2	2	3	3	3	4	4
3	0	1	2	3	4	5	7	[illegible]	12	1	1	2	2	2	3	3	3	4
4	0	1	2	3	4	5	6	7	10	1	1	2	2	2	2	3	3	4
5	0	1	2	2	3	4	5	7	9	1	1	1	2	2	2	3	3	3
6	0	1	2	2	3	4	5	6	9	0	1	1	2	2	2	2	3	3
7	0	1	1	2	3	4	5	6	8	0	1	1	2	2	2	2	3	3
8	0	1	1	2	3	4	4	6	6	0	1	1	2	2	2	2	3	3
9	0	1	1	2	3	3	4	5	7	0	1	1	2	2	2	2	2	3
10	0	1	1	2	2	3	4	5	7	0	1	1	1	2	2	2	2	3
11	0	0	1	1	2	3	3	4	6	0	1	1	1	1	2	2	2	2
12	0	0	1	1	1	2	2	3	4	0	1	1	1	1	1	1	1	2
13	0	0	0	1	1	1	1	2	2	0	0	0	1	1	1	1	1	1

FUEL MOISTURE	RATE OF SPREAD									FLAME LENGTH								
	EFFECTIVE MIDFLAME WIND (MI/H)									EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

TABLE 33--FIRE BEHAVIOR AND CONTROL INFORMATION FOR PHOTO 4-DFHD-4-CC
(FIRE BEHAVIOR INFORMATION SCALED FROM NFFL MODELS)

FUEL MOISTURE	RATE OF SPREAD: EFFECTIVE MIDFLAME WIND (MI/H) 0	2	4	6	8	10	12	14	16	FLAME LENGTH: EFFECTIVE MIDFLAME WIND (MI/H) 0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	1	3	6	9	13	16	20	26	36	1	3	4	5	5	6	7	7	9
3	1	3	5	8	11	14	17	22	31	1	2	3	4	5	5	6	7	8
4	1	2	5	7	10	13	15	20	27	1	2	3	4	4	5	5	6	7
5	0	2	4	7	9	11	14	18	25	1	2	3	4	4	5	5	6	6
6	0	2	4	5	8	11	13	17	23	1	2	3	3	4	4	5	5	6
7	0	2	4	6	8	10	12	16	22	1	2	3	3	4	4	5	5	6
8	0	2	4	6	8	10	12	15	21	1	2	3	3	4	4	4	5	6
9	0	2	3	5	7	9	11	14	20	1	2	2	3	4	4	4	5	6
10	0	2	3	5	7	8	10	13	18	1	2	2	3	3	4	4	5	5
11	0	1	3	4	6	7	9	12	16	1	2	2	3	3	3	4	4	5
12	0	1	2	3	5	6	7	10	13	1	1	2	2	3	3	3	3	4
13	0	1	2	2	3	4	5	7	9	0	1	1	2	2	2	2	3	3
14	0	0	1	1	2	2	3	3	5	0	0	1	1	1	1	1	1	2

FUEL MOISTURE	RATE OF SPREAD: EFFECTIVE MIDFLAME WIND (MI/H) 0	2	4	6	8	10	12	14	16	FLAME LENGTH: EFFECTIVE MIDFLAME WIND (MI/H) 0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	1	5	10	16	22	29	37	48	68	5	9	12	15	17	19	21	24	28
3	1	4	9	14	20	26	32	42	60	4	8	11	13	15	18	19	22	26
4	1	4	8	13	18	23	29	38	54	4	7	10	12	14	16	18	20	24
5	1	4	7	11	16	21	26	34	49	3	6	9	11	13	15	16	18	22
6	1	3	7	10	15	19	24	31	45	3	6	8	10	12	13	15	17	20
7	1	3	6	10	14	18	22	29	41	3	6	8	9	11	12	14	16	18
8	1	3	6	9	13	17	21	27	39	3	5	7	9	10	12	13	15	17
9	1	3	5	9	12	16	20	26	36	3	5	7	8	10	11	12	14	16
10	1	3	5	8	11	15	19	24	35	2	4	6	8	9	10	11	13	15
11	1	2	5	8	11	14	18	23	33	2	4	6	7	8	9	10	12	14
12	1	2	5	8	11	14	17	23	32	2	4	5	7	8	9	10	11	13
13	1	2	5	7	10	13	17	22	31	2	4	5	6	7	8	9	10	12
14	1	2	4	7	10	13	16	21	30	2	3	5	6	7	8	8	10	11
15	1	2	4	7	9	12	15	20	28	2	3	4	5	6	7	8	9	10
16	0	2	4	6	9	12	14	19	27	2	3	4	5	6	7	7	8	10
17	0	2	4	6	8	11	14	18	25	1	3	4	4	5	6	7	7	9
18	0	2	3	6	8	10	13	17	24	1	2	3	4	5	5	6	7	8
19	0	2	3	5	7	9	11	15	21	1	2	3	4	4	5	5	6	7
20	0	1	3	4	6	8	10	13	19	1	2	2	3	4	4	4	5	6
21	0	1	2	4	5	7	9	11	16	1	1	2	3	3	3	4	4	5
22	0	1	2	3	4	5	7	9	13	1	1	2	2	2	3	3	3	4
23	0	1	1	2	3	4	5	6	9	0	1	1	1	2	2	2	2	3
24	0	0	1	1	2	2	3	3	5	0	0	1	1	1	1	1	1	1

TABLE 35--FIRE BEHAVIOR AND CONTROL INFORMATION FOR PHOTO 5-[illegible]-4-CC
(FIRE BEHAVIOR INFORMATION SCALED FROM NFFR MODELS)

FUEL MOISTURE	RATE OF SPREAD — EFFECTIVE MIDFLAME WIND (MI/H)									FLAME LENGTH — EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	2	8	17	26	37	48	59	78	111	6	14	19	24	28	32	35	40	47
3	2	7	15	23	32	42	52	69	98	7	13	18	22	25	29	32	36	42
4	2	6	13	21	29	38	47	61	87	6	12	16	20	23	26	29	33	39
5	2	6	12	19	26	34	42	55	79	6	11	15	18	21	24	27	30	35
6	1	5	11	17	24	31	39	51	72	5	10	14	17	20	22	25	28	33
7	1	5	10	16	22	29	36	47	67	5	9	13	16	18	20	23	26	30
8	1	5	9	15	21	27	33	44	62	5	8	12	14	17	19	21	24	28
9	1	4	9	14	19	25	32	42	59	4	8	11	13	16	18	20	22	26
10	1	4	8	13	19	24	30	40	56	4	7	10	13	15	17	18	21	24
11	1	4	8	13	18	23	29	38	54	4	7	10	12	14	15	17	19	23
12	1	4	8	12	17	22	28	37	52	4	6	9	11	13	14	16	18	21
13	1	4	7	12	17	22	27	35	50	3	6	8	10	12	14	15	17	20
14	1	4	7	11	16	21	26	34	48	3	6	8	10	11	13	14	16	19
15	1	3	7	11	15	20	25	32	46	3	5	7	9	10	12	13	15	17
16	1	3	7	10	14	19	23	31	44	3	5	7	8	9	11	12	13	16
17	1	3	6	10	14	18	22	29	41	2	4	6	7	9	10	11	12	14
18	1	3	6	9	13	16	20	27	38	2	4	5	7	8	9	10	11	13
19	1	3	5	8	11	15	19	24	35	2	3	5	6	7	8	9	10	11
20	1	2	5	7	10	13	16	22	31	2	3	4	5	6	7	7	8	10
21	1	2	4	6	9	11	14	18	26	1	2	3	4	5	6	6	7	8
22	0	2	3	5	7	9	11	14	21	1	2	3	3	4	4	5	5	6
23	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

FUEL MOISTURE	RATE OF SPREAD: EFFECTIVE MIDFLAME WIND (MI/H)									FLAME LENGTH: EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	2	9	18	28	39	51	63	83	[illegible]	9	17	24	29	34	37	43	49	57
3	2	8	16	25	34	45	56	73	104	9	16	22	27	31	35	39	44	52
4	2	7	14	22	31	40	50	66	93	8	14	20	24	28	32	36	40	47
5	2	6	13	20	28	36	45	59	84	7	13	18	22	26	29	33	37	43
6	2	6	12	18	25	33	41	54	77	7	12	17	21	24	27	30	34	40
7	1	5	11	17	24	31	38	50	71	6	11	15	19	22	25	28	31	37
8	1	5	10	16	22	29	36	47	67	6	10	14	18	21	23	26	29	34
9	1	5	9	15	21	27	34	44	63	5	10	13	16	19	22	24	27	32
10	1	4	9	14	20	26	32	42	60	5	9	12	15	18	20	22	25	30
11	1	4	9	14	19	25	31	41	58	5	8	12	14	17	19	21	24	28
12	1	4	8	13	18	24	30	39	56	4	8	11	13	16	18	20	22	26
13	1	4	8	13	18	23	29	38	53	4	7	10	13	15	17	18	21	24
14	1	4	8	12	17	22	28	36	51	4	7	9	12	14	15	17	19	23
15	1	4	7	12	16	21	26	35	49	3	6	9	11	13	14	16	18	21
16	1	3	7	11	15	20	25	33	47	3	6	8	10	12	13	15	16	19
17	1	3	7	10	15	19	24	31	44	3	5	7	9	11	12	13	15	18
18	1	3	6	10	13	18	22	29	41	3	5	7	8	10	11	12	13	16
19	1	3	6	9	12	16	20	26	37	2	4	6	7	8	9	10	12	14
20	1	2	5	8	11	14	18	23	33	2	4	5	6	7	8	9	10	12
21	1	2	4	7	9	12	15	20	28	2	3	4	5	6	7	8	9	10
22	0	2	3	5	7	9	12	15	22	1	2	3	4	5	5	6	7	8
23	0	1	2	4	5	7	8	11	16	1	2	2	3	3	4	4	5	6
24	0	1	1	2	3	4	4	6	8	0	1	1	2	2	2	2	3	3

Douglas-fir--Hardwood

Size Class 4

Partial Cut

Tables 37 Through 42

(Corresponds to Photo Series 1-DFHD-4-PC to 6-DFHD-4-PC in Maxwell and Ward 1976)

FUEL MOISTURE	RATE OF SPREAD: EFFECTIVE MIDFLAME WIND (MI/H)									FLAME LENGTH: EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

TABLE 38--FIRE BEHAVIOR AND CONTROL INFORMATION FOR PHOTO 2-DFHD-4-PC
(FIRE BEHAVIOR INFORMATION SCALED FROM NFDR MODELS)

FUEL MOISTURE	RATE OF SPREAD									FLAME LENGTH								
	EFFECTIVE MIDFLAME WIND (MI/H)									EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	1	5	11	17	24	31	39	51	72	2	5	6	8	9	10	11	13	15
3	1	5	9	15	21	27	34	45	64	2	4	6	7	8	9	10	12	14
4	1	4	8	13	19	25	31	40	57	2	4	5	6	8	9	9	11	13
5	1	4	8	12	17	22	28	36	52	2	3	5	6	7	5	9	10	12
6	1	3	7	11	16	20	25	33	47	2	3	4	5	6	7	8	9	11
7	1	3	6	10	14	19	23	31	44	2	3	4	5	6	7	7	8	10
8	1	3	6	10	13	18	22	29	41	1	3	4	5	5	6	7	8	9
9	1	3	6	9	13	17	21	27	39	1	3	4	4	5	6	6	7	9
10	1	3	5	9	12	16	20	26	37	1	2	3	4	5	5	6	7	8
11	1	3	5	8	12	15	19	25	35	1	2	3	4	4	5	6	6	7
12	1	2	5	8	11	15	18	24	34	1	2	3	4	4	5	5	6	7
13	1	2	5	8	11	14	18	23	33	1	2	3	3	4	4	5	6	6
14	1	2	5	7	10	14	17	22	31	1	2	3	3	4	4	5	5	6
15	1	2	4	7	10	13	16	21	30	1	2	2	3	3	4	4	5	6
16	1	2	4	7	9	12	15	20	29	1	2	2	3	3	3	4	4	5
17	0	2	4	6	9	12	14	19	27	1	1	2	2	3	3	4	4	5
18	0	2	4	6	8	11	13	18	25	1	1	2	2	3	3	3	4	4
19	0	2	3	5	7	10	12	16	23	1	1	2	2	2	3	3	3	4
20	0	1	3	5	7	9	11	14	20	1	1	1	2	2	2	2	3	3
21	0	1	3	4	6	7	9	12	17	0	1	1	1	2	2	2	2	3
22	0	1	2	3	4	6	7	9	13	0	1	1	1	1	1	2	2	2

FUEL MOISTURE	RATE OF SPREAD: EFFECTIVE MIDFLAME WIND (MI/H)									FLAME LENGTH: EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	1	5	10	16	23	30	37	49	69	4	7	10	12	14	16	18	20	24
3	1	4	9	14	20	26	33	43	61	3	6	9	11	13	15	16	18	21
4	1	4	8	13	18	23	29	38	55	3	6	8	10	12	13	15	17	20
5	1	4	7	12	16	21	26	35	49	3	5	7	9	11	12	13	15	18
6	1	3	7	11	15	19	24	32	45	3	5	7	8	10	11	12	14	17
7	1	3	6	10	14	18	22	29	42	2	5	6	8	9	10	11	13	15
8	1	3	6	9	13	17	21	27	39	2	4	6	7	9	10	11	12	14
9	1	3	5	9	12	16	20	26	37	2	4	6	7	8	9	10	11	13
10	1	3	5	8	12	15	19	25	35	2	4	5	6	7	8	9	11	12
11	1	2	5	8	11	14	18	24	34	2	3	5	6	7	8	9	10	12
12	1	2	5	8	11	14	17	23	32	2	3	4	6	6	7	8	9	11
13	1	2	5	7	10	13	17	22	31	2	3	4	5	6	7	8	9	10
14	1	2	4	7	10	13	16	21	30	1	3	4	5	6	6	7	8	9
15	1	2	4	7	9	12	15	20	29	1	3	4	4	5	6	7	7	9
16	0	2	4	6	9	12	15	19	27	1	2	3	4	5	5	6	7	8
17	0	2	4	6	8	11	14	18	26	1	2	3	4	4	5	5	6	7
18	0	2	4	6	8	10	13	17	24	1	2	3	3	4	4	5	6	7
19	0	2	3	5	7	9	12	15	22	1	2	2	3	3	4	4	5	6
20	0	1	3	4	6	8	10	13	19	1	1	2	3	3	3	4	4	5
21	0	1	2	4	5	7	9	11	16	1	1	2	2	2	3	3	4	4
22	0	1	2	3	4	6	7	9	13	1	1	1	2	2	2	2	3	3
23	0	1	1	2	3	4	5	6	9	0	1	1	1	1	2	2	2	2
24	0	0	1	1	2	2	3	3	5	0	0	1	1	1	1	1	1	1

TABLE 40--FIRE BEHAVIOR AND CONTROL INFORMATION FOR PHOTO 4-DFHD-4-PC
(FIRE BEHAVIOR INFORMATION SCALED FROM NFDR MODELS)

FUEL MOISTURE	RATE OF SPREAD									FLAME LENGTH								
	EFFECTIVE MIDFLAME WIND (MI/H)									EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	2	8	16	25	36	46	53	76	108	5	9	13	16	18	20	23	26	30
3	2	7	14	22	31	41	51	67	95	4	8	11	14	16	19	21	23	27
4	2	6	13	20	28	37	46	60	85	4	8	10	13	15	17	19	21	25
5	2	6	11	18	25	33	41	54	77	4	7	10	12	14	16	17	19	23
6	1	5	11	17	23	30	38	49	70	3	6	9	11	13	14	16	18	21
7	1	5	10	15	21	28	35	46	65	3	6	8	10	12	13	15	17	20
8	1	5	9	14	20	26	33	43	61	3	5	8	9	11	12	14	15	18
9	1	4	9	14	19	25	31	41	58	3	5	7	9	10	11	13	14	17
10	1	4	8	13	18	24	29	39	55	3	5	7	8	9	11	12	13	16
11	1	4	8	12	17	23	28	37	53	2	4	6	8	9	10	11	13	15
12	1	4	8	12	17	22	27	[illegible]	[illegible]	2	4	6	7	8	9	10	12	14
13	1	4	7	12	16	21	26	34	49	2	4	5	7	8	9	10	11	13
14	1	3	7	11	15	20	25	33	47	2	4	5	6	7	8	9	10	12
15	1	3	7	11	15	19	24	32	45	2	3	5	6	7	8	8	9	11
16	1	3	6	10	14	18	23	30	43	2	3	4	5	6	7	8	9	10
17	1	3	6	9	13	17	22	28	40	2	3	4	5	6	6	7	8	9
18	1	3	6	9	12	16	20	26	37	1	3	3	4	5	6	6	7	8
19	1	3	5	8	11	15	18	24	34	1	2	3	4	4	5	6	6	7
20	1	2	4	7	10	13	16	21	30	1	2	3	3	4	4	5	5	6
21	0	2	4	6	8	11	14	18	25	1	2	2	3	3	4	4	4	5
22	0	1	3	5	7	9	11	14	20	1	1	2	2	2	3	3	4	4

FUEL MOISTURE	RATE OF SPREAD: EFFECTIVE MIDFLAME WIND (MI/H)									FLAME LENGTH: EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	2	6	12	20	27	36	45	58	83	5	9	12	15	17	20	22	25	29
3	1	5	11	17	24	32	39	52	73	4	8	11	14	16	18	20	22	26
4	1	5	10	15	22	28	35	46	65	4	7	10	12	14	16	18	20	24
5	1	4	9	14	19	25	32	42	59	4	7	9	11	13	15	17	19	22
6	1	4	8	13	17	23	29	38	54	3	6	8	10	12	14	15	17	20
7	1	4	7	12	16	22	27	35	50	3	6	8	10	11	13	14	16	19
8	1	3	7	11	15	20	25	33	47	3	5	7	9	10	12	13	15	17
9	1	3	7	10	15	19	24	31	44	3	5	7	8	10	11	12	14	16
10	1	3	6	10	14	18	23	30	42	2	5	6	8	9	10	11	13	15
11	1	3	6	10	13	17	22	28	41	2	4	6	7	9	10	11	12	14
12	1	3	6	9	13	17	21	27	39	2	4	6	7	8	9	10	11	13
13	1	3	6	9	12	16	20	26	38	2	4	5	6	7	8	9	11	12
14	1	3	5	8	12	16	19	25	36	2	3	5	6	7	8	9	10	12
15	1	3	5	8	11	15	19	24	35	2	3	4	5	6	7	8	9	11
16	1	2	5	8	11	14	18	23	33	2	3	4	5	6	7	7	8	10
17	1	2	5	7	10	13	17	22	31	1	3	4	5	5	6	7	8	9
18	1	2	4	7	9	12	15	20	29	1	2	3	4	5	5	6	7	8
19	0	2	4	6	9	11	14	18	26	1	2	3	4	4	5	5	6	7
20	0	2	3	5	8	10	12	16	23	1	2	3	3	4	4	5	5	6
21	0	1	3	5	6	8	10	14	19	1	2	2	3	3	3	4	4	5
22	0	1	2	4	5	7	8	11	15	1	1	2	2	2	3	3	3	4
23	0	1	2	3	4	5	6	8	11	0	1	1	1	2	2	2	2	3
24	0	0	1	1	2	2	3	4	6	0	0	1	1	1	1	1	1	2

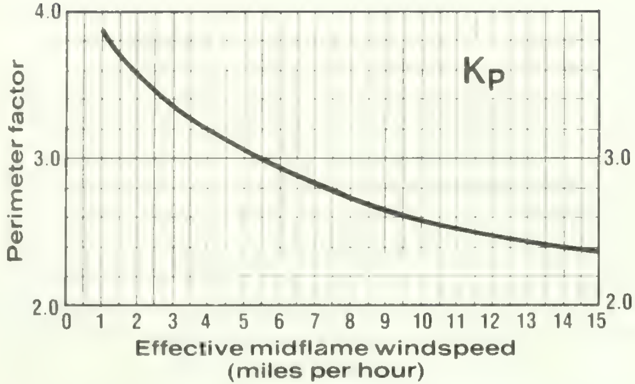
TABLE 42--FIRE BEHAVIOR AND CONTROL INFORMATION FOR PHOTO 6-DFHD-4-PC
(FIRE BEHAVIOR INFORMATION SCALED FROM NFFL MODELS)

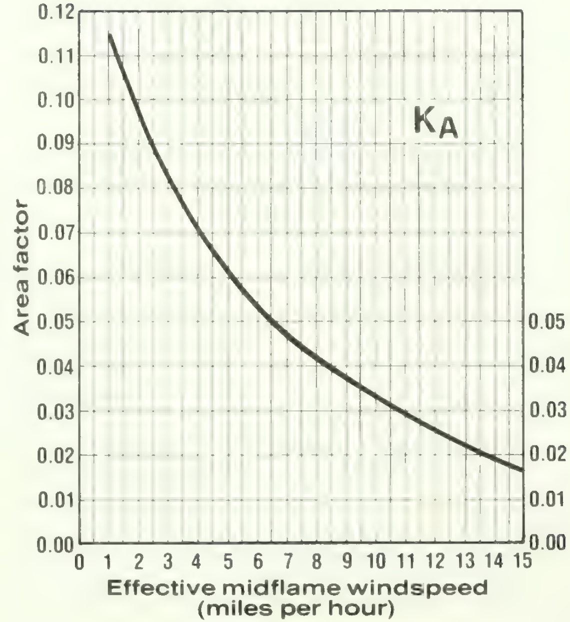
FUEL MOISTURE	RATE OF SPREAD									FLAME LENGTH								
	EFFECTIVE MIDFLAME WIND (MI/H)									EFFECTIVE MIDFLAME WIND (MI/H)								
	0	2	4	6	8	10	12	14	16	0	2	4	6	8	10	12	14	16
PERCENT	CHAINS PER HOUR									FEET								
2	1	3	6	9	12	15	19	24	34	1	3	4	4	5	6	6	7	8
3	1	3	5	8	10	13	16	21	29	1	2	3	4	4	5	5	6	7
4	0	2	4	7	9	12	14	18	26	1	2	3	3	4	4	5	6	6
5	0	2	4	6	8	11	13	17	23	1	2	3	3	4	4	5	5	6
6	0	2	4	6	8	10	12	16	22	1	2	3	3	4	4	4	5	6
7	0	2	4	5	7	10	12	15	21	1	2	2	3	3	4	4	5	6
8	0	2	3	5	7	9	11	14	20	1	2	2	3	3	4	4	5	5
9	0	2	3	5	7	9	10	13	19	1	2	2	3	3	4	4	4	5
10	0	1	3	4	6	8	10	12	17	1	2	2	3	3	3	4	4	5
11	0	1	3	4	5	7	8	11	15	1	1	2	2	3	3	3	4	4
12	0	1	2	3	4	5	7	9	12	1	1	2	2	2	3	3	3	4
13	0	1	1	2	3	4	5	6	8	0	1	1	1	2	2	2	2	3
14	0	0	1	1	1	1	2	2	3	0	0	0	1	1	1	1	1	1

Appendix 1

Fire Perimeter and Area Calculation Graphs and Formulas

(Adapted from Fire Behavior Officer's Field Reference, National Interagency Fire Training Center, Marana, Arizona)





P = Perimeter (chains)

$$P = K_P D$$
$$= K_P(R \times T)$$

A = Area (acres)

$$A = K_A D^2$$
$$= K_A(R \times T)^2$$

WHERE:

K_P = Perimeter factor
R = Rate of spread (chains per hour)
T = Time (hour); 1-hour maximum
K_A = Area factor
D = R x T; spread distance (chains)

Appendix 2

Resistance to control ratings, flame length adjustment factor, slope adjustment factor, and conversion of resistance to control rating values to chains per hour of line constructed by one person

The resistance to control rating (table 43) times flame length adjustment factor (table 44) times slope adjustment factor (table 45) equals the adjusted rating. Use table 46 to convert adjusted rating to actual resistance to control.

Table 43--Fuel resistance to control ratings by photo number[1]

PHOTO NUMBER	RATING	PHOTO NUMBER	RATING
1-DF-4-CC	4	1-DF-1-TH	6
2-DF-4-CC	7	2-DF-1-TH	18
3-DF-4-CC	6	3-DF-1-TH	7
4-DF-4-CC	13	4-DF-1-TH	19
5-DF-4-CC	11		
6-DF-4-CC	9	1-DFHD-4-CC	4
7-DF-4-CC	20	2-DFHD-4-CC	4
8-DF-4-CC	21	3-DFHD-4-CC	6
9-DF-4-CC	31	4-DFHD-4-CC	6
10-DF-4-CC	27	5-DFHD-4-CC	12
		6-DFHD-4-CC	13
1-DF-4-PC	4	7-DFHD-4-CC	13
2-DF-4-PC	5		
3-DF-4-PC	4	1-DFHD-4-PC	3
4-DF-4-PC	9	2-DFHD-4-PC	6
5-DF-4-PC	8	3-DFHD-4-PC	7
6-DF-4-PC	11	4-DFHD-4-PC	9
7-DF-4-PC	15	5-DFHD-4-PC	12
8-DF-4-PC	25	6-DFHD-4-PC	15
9-DF-4-PC	18		
1-DF-3-PC	4		
2-DF-3-PC	7		
3-DF-3-PC	7		
4-DF-3-PC	23		
5-DF-3-PC	17		
6-DF-3-PC	18		

Flame length (feet)	0-4	5-8	9-12	13+
Adjustment factor	1	1.5	2.0	3.0

Table 45--Slope adjustment factor

Slope (percent)	0-30	31-60	61-75	75+
Adjustment factor	1	1.2	1.5	1.9

Table 46--Conversion of rating values to chains per hour of line constructed by 1 person

Adjusted rating values	Chains per hour	Adjusted rating values	Chains per hour
1	12.00	13	0.92
2	6.00	14	.86
3	4.00	15	.80
4	3.00	16	.75
5	2.40	17	.71
6	2.00	18	.67
7	1.70	19	.63
8	1.50	20	.60
9	1.30	25	.48
10	1.20	30	.40
11	1.10	35	.34
12	1.00	40	.30

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Abstract

A report of special interest to fishery biologists, resource managers, hydrologists, and road engineers, this bibliography lists publications pertinent to road crossings of salmon and trout streams. Topics include bridge and culvert installation, design criteria, mechanics, hydraulics, and economics, as well as their biological effects.

Keywords: Bibliographies (fish habitat), fish habitat, forest engineering.

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General Technical Report PNW-117

Fish Passage at Road Crossings: An Annotated Bibliography

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and

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October 1980

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Forest Service, U.S. Department of Agriculture, Portland, Oregon

References by Subject

This annotated bibliography was prepared as a guide to the literature available on problems with fish passage at road crossings. Crossings that include bridge and culvert installations and adaptations of culverts are emphasized. A limited selection of the general literature on fish-passage devices is also included.

We have attempted to review and abstract a broad spectrum of the literature to provide field biologists, engineers, and land managers with a guide to what is available. Additions to the current list would be appreciated.

Some relevant information is in relatively obscure technical reports. We were usually able to obtain copies of the cited papers from the producing agency; most of them are on file at the Forestry Sciences Laboratory, USDA Forest Service, P.O. Box 909, Juneau, Alaska 99802.

References are listed by author and number. A list of general topics and the number corresponding to the source are included.

Adamovich, L., R. P. Willington, and D. Lacate.
1973. Bibliography on forest roads and the environment. Fac. For. Univ. B.C., Vancouver. Unpubl. ms., 25 p.

A list is given of published and unpublished material on most aspects and effects of forest roads through 1973. Topics include esthetics, aerial photo interpretation, bridges, construction, cut and fill procedures, and various effects on fisheries.

Bell, M. C.
1973. Fisheries handbook of engineering requirements and biological criteria. Fish. Eng. Res. Program. Corps Eng., North Pac. Div., Portland, Oreg.

A wide range of information on fisheries and engineering problems is included. Areas applicable to fish passage are discussed in several chapters. These include passage around dams, fishways and other conduits, swimming speeds, and velocity barriers. Chapter 31 deals specifically with culverts and briefly discusses some of the hydraulic characteristics of culverts. Some general guidelines for culvert installation are provided: Culverts should be installed close to zero gradient; average velocities with a slope of 0.5 percent are 4.8 to 2.6 ft/s, which will allow fish to pass; culvert floor roughness should approximate natural streambed; and a minimum swimming depth of 12 inches should be allowed. Darkness in a culvert is not a block to fish passage.

Blahm, T. H.
1963. Passage of salmon fingerlings through small tunnels. Trans. Am. Fish. Soc. 92(1):302-303.

Tests were conducted in an artificial channel to determine the optimum combination of water velocity and light that would be most effective for downstream passage of salmon fingerlings through small tunnels. Higher velocities (3.0 to 3.5 ft/s) in combination with downstream light induced the highest percentage of downstream passage.

4. Clay, C. H.
1961. Design of fishways and other fish facilities. Dep. Fish. Can., Ottawa. 301 p.

This handbook of fish-passage devices primarily deals with artificial and natural obstructions. Design criteria for fishways, vertical slot passages, entrances, baffles, and exits are discussed. Other chapter topics include fish locks, weirs, barrier dams, fish screens, and artificial spawning channels. A brief review of elementary hydraulics is contained in an appendix.

5. Collins, G. B., and C. H. Elling.
1960. Fishway research at the fisheries-engineering research laboratory. U.S. Fish and Wildl. Serv. Circ. 98. 17 p.

Results of 4 years of research on fishway problems, rates of movement of salmonids ascending fishways, and spatial requirements of fish are given. Experiments to measure fishway capacity are described. The effect of fishway slope and length on fish performance and physiology were measured in "endless" fishways. Preference of salmonids for water velocities and light conditions revealed marked differences among species. Effects of light and water velocity on rates of passage through channels and fishways are described. Experiments on fingerling passage and the testing of full-scale prototype fishway designs are discussed.

6. Collins, G. B., J. R. Gauley, and C. H. Elling.
1962. Ability of salmonids to ascend high fishways. Trans. Am. Fish. Soc. 91(1):1-7.

Ability and persistence of salmonids to ascend pool-and-overfall fishways were measured in experimental "endless" structures in which fishways of any height could be simulated. Rate of ascent of all fish tested increased after an initial period of experience in the fishway. Measurement of blood lactate in the exercised fish showed no evidence of fatigue. Practical significance of the data in relation to fishway design is discussed.

7. Dane, B. G.
1978. A review and resolution of fish passage problems at culvert sites in British Columbia. Fish. and Mar. Serv. Tech. Rep. 810, 126 p.

Report includes guidelines for culvert design and installation, which describe salmonid passage requirements and hydraulic parameters. Five types of culverts are described. Their characteristics are compared with photos and sketches. Author described type, cause, and effect of obstructions in the spawning/rearing area, as well as effects of habitat and hydraulic instability. Recommendations are made for the installation of culverts to avoid conflict with fish use in the stream during construction. For a condensed version of this report, see Dane, Culvert guidelines: recommendations for the design and installation of culverts in British Columbia to avoid conflict with anadromous fish. Fish. and Mar. Serv. Tech. Rep. 811. 57 p.

8. Dass, P.
1970. Analysis of slot orifice fishways. M.S. thesis. Univ. Idah
Moscow. 101 p.

Criteria for a slot orifice fishway developed. Size and space of orific can be designed to create flow conditions satisfactory for fish passag The slot orifice fishway functioned well in a wide range of discharges a should not have any serious silting problems. Values of drag coeffients the slot orifice constrictions were evaluated by model studies.

9. Dryden, R. L., and C. S. Jessop.
1974. Impact analysis of the Dempst Highway culvert on the physical envi ment and fish resources of Frog Cree Fish. and Mar. Serv., Can. Dep. Environ./Fish. Oper. Dir./Cent. Reg. Tech. Rep. Ser. CEN/T-74-5, 59 p.

Improper culvert design and its effe on hydrology and fish populations of Frog Creek, Northwest Territories, Canada, are discussed. The effects documented are on migration of fish (northern pike, Esox lucius, and bro whitefish, Coregonus nasus) and stre bank stability attributable to water velocities in excess of 1.5 m/s (5 ft/s). The causes were high flows through the culvert and energy dissipation at the outfall. Biological measurements made on northern pike a whitefish included age, growth, movement, and gonad development.

10. Dryden, R. L., and J. N. Stein.
1975. Guidelines for the protection the fish resources of the Northwest Territories during highway constructi and operation. Fish. and Mar. Serv., Can. Dep. Environ./Fish. Oper. Dir./ Cent. Reg./Tech. Rep. Ser. CEN/ T-75-
32 p.

These guidelines are intended to aid highway designers; they are applicable to all water courses that flow for at least one period each year, as well as all highway-related stream alterations, including both temporary and permanent road crossings, culverts, right-of-way approaches, and gravel removal. The study was confined to Mackenzie Valley, Northwest Territories, streams and species. Statistical conclusions may be site specific; however, the biological and technical guidelines are universal in dealing with highway design and fish-passage problems.

Engel, P.
1974. Fish passage facilities for culverts of the Mackenzie Highway. Dep. Environ., Hydraul. Div., Can. Cent. Inland Waters, 33 p. Burlington, Ont.

The study evaluated three types of fish-passage facilities for large culverts--spoilers, offset baffles, and side baffles. The relation of hydraulic characteristics to swimming speeds of fish is described and modeled. Effectiveness of each design was proportional to gradient. Maximum recommended slope was 5 percent. Suggestions for application of elliptical and arch culverts to fish-passage facilities are also made. Recommendations and limitations of each device are given. Problems with debris and sediment may occur. Ice may be more of a problem with side baffles. Data for swimming speed (burst), friction factors, and velocities are given, as are design diagrams.

Evans, W. A., and F. B. Johnson.
1974. Fish migration and fish passage: A practical guide to solving fish passage problems. USDA For. Serv. Reg. 5, 43 p.

Practical problems of fish passage through and over natural and artificial structures in streams are discussed. Fish barriers are illustrated, and barriers from road crossings and methods for correcting them are described. The authors provide a useful guide for installation of culverts and stream crossings to provide for fish passage. Figures and tables are given to provide gradient, velocity, and other data for various culvert sizes.

13. Gauley, J. R.
1966. Effects of water velocity on passage of salmonids in a transportation channel. U.S. Dep. Int., Fish. and Wildl. Serv., Bur. Comm. Fish., Fish Bull. 66(1):59-63.

Passage times of chinook salmon, sockeye salmon, and steelhead trout through a test channel were compared at velocities of 1 and 2 ft/s. The test channel was 4 feet wide, 6 feet deep, and 100 feet long. Passage times did not differ significantly with water velocity for any of the three species. The two salmon species moved faster than steelhead trout at both water velocities. The author concluded that 1 ft/s is as suitable as 2 ft/s for fish passage.

14. Gauley, J. R., and C. S. Thompson.
1962. Further studies on fishway slope and its effect on rate of passage of salmonids. U.S. Dep. Int., Fish and Wildl. Serv., Bur. Comm. Fish., Fish. Bull. 63(1): 45-62.

Rates of passage of chinook and sockeye salmon and steelhead trout were studied in 1:16- and 1:8-slope, pool-and-overfall fishways. In general, the passage through the 1:8-slope fishway with a 1-foot rise between pools was as fast as, or faster than, in the 1:16-slope with a 1-foot rise. When the rise between pools was increased to 1.5 feet in the 1:8-slope fishway, chinook and sockeye passage was slower. The "Dalles-type" weir crests (3.3-m, 4-ft pool

width) in a 1:16-slope fishway appeared to accelerate chinook passage. Chinook and sockeye displayed seasonal differences in passage time.

15. Gauley, J. R., C. R. Weaver, and C. S. Thompson.
1966. Research on fishway problems, May 1960 to April 1965. 3d Prog. Rep. Fish. Eng. Res. Program, Corps Eng., North Pac. Div., p. 29-66. Portland, Oreg.

Research program sponsored by the U.S. Army Corps of Engineers to investigate design criteria for fish-passage facilities for hydroelectric projects is reviewed. The primary objective was to provide basic information on the behavior of fish and what is required for fish passage. Major emphasis was on cost reduction of fish-passage facilities without reduction of efficiency to pass fish. Passage times for various salmonids through several fish-ladder designs and the response of salmonids to vertical and horizontal orifices in fishways are reviewed. Counting and identification studies at fishways are also discussed.

16. Gebhards, S., and J. Fisher.
1972. Fish passage and culvert installations. Idaho Fish and Game Rep., 12 p.

The authors list fish blocks resulting from improper culvert installation that occur at the outfall, within the culvert, and at the inlet. Criteria for installation, including timing of construction, design, and placement to insure fish passage, are given. Design criteria include gradient, velocity, and depth. Use of baffles, separator walls, and multiple installations are discussed. Velocities and distances impeding fish passage are graphed. A design for culvert baffles is also presented.

17. Gregory, R. W., and J. Trial.
1975. Effect of zinc-coated culvert on vertebrate and invertebrate fauna selected Maine streams. Completion R Land and Water Resour. Inst., 18 p. Univ. Maine, Orono. Sept. 1975.

Effect of zinc loss from galvanized culverts on vertebrate and invertebr fauna was investigated. Results indicated that corrosion of galvanized culverts significantly increased zin concentrations in stream water, particularly in newer culverts, althoug culverts 5-6 years old also showed significant loss of zinc. Highest zi concentration was correlated with hi temperature and low flow. No adverse effect of increased zinc concentrati was documented for either fish distr tion or invertebrate diversity or abundance, with the possible excepti of Spongilla. Levels of zinc were at times above the avoidance threshold (0.05 ppm) of Atlantic salmon.

18. Harrison, M. B.
1972. Analysis of a skewed slot orifice. M.S. thesis. Univ. Idaho, Moscow. 89 p.

Design criteria for a skewed slot-orifice fishway exit are developed. T fishway exit can be constructed using these criteria in culvert wingwalls. The outlet terminates at a skew angle it can be designed to create flow con ditions necessary for fish passage. Values of slot-orifice contraction ratios ranged from 0.65 to 0.82 of th culvert width; culvert slope varied from 1.5 to 4.5 percent; skew angles ranged from 30 to 75^{o}; and three lateral positions of the fishway chan were tested. Dimensional analysis was used to determine the significant des parameters. Design curves that displa the relationship between the backwate ratio (H/h) and the Froude number are presented. The design curves and an equation, based on the momentum principle, are used to design two types of

skewed-orifice exits. One problem uses the same contraction ratio for the skewed-exit and normal-slot orifices placed downstream; the other uses different values of contraction ratio for the skewed-exit and normal-slot orifices downstream. Necessary criteria for suitability of flow for fish passage are also discussed.

Katopodis, C., P. R. Robinson, and B. G. Sutherland.
1978. A study of model and prototype culvert baffling for fish passage. Can. Fish. and Mar. Serv. Tech. Rep. 828. 78 p.

A hydraulic-model study tested and developed a set of offset and spoiler baffles to aid fish passage through culverts. Based on the model-study recommendations, they were installed at the Mackenzie Highway crossing of the Redknife River. Field testing showed the effectiveness of both baffle types is inversely proportional to culvert slope. Maximum recommended slope is 5 percent. A method of judging adequacy of baffles is provided. The problems created by ice, debris, and sediment are presented. The list of figures includes design dimensions, installation, and water-surface profiles for offset and spoiler baffles, as well as cross sectional velocity distributions.

Kay, A. R., and R. B. Lewis.
1970. Passage of anadromous fish through highway drainage structures. Calif. Div. Highw., Dist. 01 Res. Rep. 629110, 15 p.

Authors discuss factors that impede passage of migrating fish and establish design criteria for fish passage. Graphs and tables are included. A field investigation of 40 existing culverts was conducted and their fish-passage characteristics were evaluated.

21. Lauman, J. E.
1976. Salmonid passage at stream-road crossings: A report with department standards for passage of salmonids. Oreg. Dep. Fish and Wildl., 78 p. Portland.

The author's review provides guidance for bridge and culvert projects. Causes and solutions for fish-passage problems--excessive water velocity, inadequate water depth, excessive entrance jump--are discussed. Structural guidelines for location, type, and size of fishway are included. Recommended velocities for adults and juveniles, as well as comprehensive tables and figures, are presented.

22. Leedy, D. L.
1975. Highway-wildlife relationships, vol. 1. A state-of-the-art report. U.S. Dep. Trans., Fed. Highw. Adm. Tech. Rep. FHWA-RD-76-4, 183 p.

An extensive review of effects of highways, including logging roads and construction, on fish and wildlife is given. Also included is habitat created by highway right-of-way. A discussion of erosion, sedimentation, and loss of wildlife habitat is given through a review of existing literature. Roads are identified as a major source of sediment and responsible for drainage of large areas of wetlands. A set of recommendations for additional research on highway and fish and wildlife topics is listed in addition to general guidelines for management.

23. Leedy, D. L., T. M. Franklin, and E. C. Hekimian.
1975. Highway-wildlife relationships, vol. 2. An annotated bibliography. U.S. Dep. Trans., Fed. Highw. Adm. Tech. Rep. FHWA-RD-76-5, 417 p.

A group of 794 references pertaining to the relation of wildlife and fish to highways and highway construction are abstracted. Major topic areas are: (I) The highway system: effects on and relation to fish and wildlife; (II) Opportunities for enhancing fish and wildlife and mitigating or reducing damage to the resource; and (III) Environmental considerations and evaluations in highway planning, construction, and operation.

24. Long, C. W.
1959. Passage of salmonids through a darkened fishway. Fish and Wildl. Serv. Spec. Sci. Rep.-Fish. 300, 9 p. Washington, D.C.

An experiment to produce specific information on rate of ascent of salmonids through a darkened fishway was conducted in a short, pool-and-overfall fishway without submerged orifices. The fish (98 percent steelhead trout) negotiated the 6-pool fishway significantly faster in near-total darkness than in light conditions approximating a bright, cloudy day.

25. Lowman, B. J.
1974. Investigation of fish passage problems through culverts. USDA For. Serv. Equip. Dev. Cent., Proj. Rec. ED&T 2427, 17 p. Missoula, Mont.

The author reviewed problems related to culvert installation, requirements for fish passage including recommended velocities, and corrective measures. Baffles in culverts are discussed with replies from various agencies to a questionnaire on fish-passage problems and use of baffles in culverts. Economic value of spawning areas is reviewed in an appendix.

26. McClellan, T. J.
1970. Fish passage through highway culverts. U.S. Dep. Trans., Fed. Highw. Adm. and Oreg. State Game Com 16 p. Portland.

A review of 62 culverts installed by several agencies in Oregon was made to determine effectiveness of instal lation to pass fish and (2) to evalu which types were most effective, sim plest to install, and least expensiv install and maintain. Review include round pipe, single and double culver with baffles or other special device plated arches (with both open and closed bottoms), and a few nonculver installations. The author concluded that stream condition at inlet and outlet may override design in import Controlling factors for fish passage were velocity, length, slope, and hea water and tailwater conditions. Desc tion of culverts reviewed, problems, and comments on fish passage are giv Evaluation forms with photographs are provided in the appendix.

27. McKinley, W. R., and R. D. Webb.
1956. A proposed correction of migratory fish problems at box culverts. Wash. Dep. Fish. Fish Res. Pap. 1(4):33-45.

The authors discuss culvert standards and methods of culvert correction. Model culvert studies, fishway criter and an experiment on grading of baffl are included. Baffle arrangements--types, sizes, dimensions, and so on--are discussed at length.

28. Mavis, F. T.
1943. The hydraulics of culverts. P State Coll. Bull. 56, 34 p.

Two hypotheses are tested: (1) When t culvert flows partly full and the inl serves as a control section, the discharge is a function of the elevation

of the headwater pond above the invert of the culvert at the inlet for a given culvert; and (2) The culvert flows entirely full, and for a given culvert the discharge is a function only of the difference between headwater and tailwater levels. The report includes extensive tests of culvert hydraulics: discharge of culverts flowing partly full, or flowing full and submerged; calculations for free discharge with outlet flowing full; and transitions between categories of flow. The paper includes sketches and tables.

Metsker, H. E.
1970. Fish versus culverts. USDA For. Serv. Eng. Tech. Rep. ETR-7700-5, 19 p. Washington, D.C.

This report, directed toward resource managers, illustrates some fishery problems associated with culverts and gives some solutions to them. The author suggests use of multiple culverts, stacked culverts, outlet control, downstream barriers, and baffles to facilitate fish passage.

Otis, M. B., and D. G. Pasko.
1964. Suggested measures for minimizing damage to fishing streams from highway projects. N.Y. State Conserv. Dep., Div. Fish and Game, Bur. Fish, 4 p. Albany.

The authors include a series of recommendations for streambank stabilization, bridge and culvert installation, gravel removal (generally not recommended), and streambank cover and shelter improvements.

. Sheridan, W. L.
1969. Benefit/cost aspects of salmon habitat improvement in the Alaska region. USDA For. Serv., Reg. 10, 47 p. Juneau.

A method is presented for benefit/cost analysis of projects to improve habitat, whereby funds can be allotted to obtain the highest dollar return on the investment. The Shrode Creek fishway is evaluated.

32. Shoemaker, R. H.
1956. Hydraulics of box culverts with fish-ladder baffles. Natl. Res. Counc., Highw. Res. Board Proc. 35:196-209.

Placement of transverse baffles in box culverts to provide fish passage has become increasingly necessary in recent years. Model studies were made to determine design factors for baffled culverts related to baffle height and spacing, and to develop hydraulically efficient baffle shapes for use in culverts. The results of the studies, based on the treatment of baffles as roughness in a rectangular conduit, were obtained in the form of velocity-head coefficients--one dependent on and the other independen of friction effects.

33. Skeesick, D. G.
1970. The fall immigration of juvenile coho salmon into a small tributary. Oreg. Fish Comm. Res. Rep. 2(1):90-95.

An upstream-downstream trap was monitored for 10 years; each fall, an upstream migration of large juvenile coho occurred. An average of 62.6 percent survived and returned downstream in the spring as smolts; they averaged 14 mm longer than native stock. The recapture rate of adults that had been upstream-migrant juveniles was 0.3 percent and for the native stock it was 0.8 percent. The author theorized that (1) the immigrant juveniles had spent the summer in the main stream where they grew rapidly; (2) they entered the tributary in the fall to escape high water in the main stream; and (3) as adults, they returned to their natal stream rather than to the study stream. Observations from two other river

systems appear to substantiate the behavior pattern and suggest that other species may have similar habits.

34. Slatick, E.
1970. Passage of adult salmon and trout through pipes. U.S. Fish and Wildl. Serv. Spec. Sci. Rep.-Fish. 592, 18 p.

This study determined (1) if adult salmon and trout would use a pipe as a passageway, and (2) how the conditions at the entrance and within the pipe--such as diameter and length, illumination, and flow would influence passage. The pipes were 0.3, 0.6, and 0.9 m in diameter and 27.4 to 82.3 m long. Chinook salmon, sockeye salmon, coho salmon, and steelhead trout passed through unilluminated pipes up to 82.3 m long. Only steelhead appeared to benefit from illumination. For distances up to 82.3 m, a 0.6-m diameter pipe was large enough to pass all salmon and trout. The fish would not readily enter a 0.3-m pipe until special conditions of water velocity and transition from pool to pipe were provided.

35. Slatick, E.
1971. Passage of adult salmon and trout through an inclined pipe. Trans. Am. Fish. Soc. 100(3):448-455.

The author examined a passageway at Bonneville Dam on the Columbia River, which required a descent and ascent by migrating adult salmon and trout. The influence of water velocities on fish passage was measured with velocities of 0.30, 0.76, and 1.22 m/s, and the relation between performance and length of fish was determined by comparing median passage times of large and small fish. From 64 to 100 percent of the fish passed through the pipe in 45 minutes. Median passage times ranged from 3-23 minutes. Chinook salmon passed through the pipe most rapidly at the 0.76-m/s flow; coho salmon and steelhead trout passed through at 1.22 m/s. Sockeye salmon passed through equally well a flows of 0.76 and 1.22 m/s. No sign cant differences were demonstrated b tween median passage times of small large chinook salmon, sockeye salmon coho salmon, or summer steelhead tro Results of this experiment indicated that if proper flow conditions are p vided, a large percentage of migrati adult salmon and steelhead will pass through an inclined pipe requiring a descent and ascent of about 5.2 m.

36. Tollefson, T. C.
1966. Facilities at culvert installations. Wash. Dep. Fish. 8 p.

Report includes basic recommendation for placement of culverts, use of baffles, downstream controls, separa walls, and multiple installations, p drawings of these facilities.

37. Trefethen, P. S.
1968. Fish passage research, review progress, 1961-66. U.S. Dep. Int., Fish and Wildl. Serv., Bur. Commer. Fish., Circ. 254, 24 p. Washington, D.C.

Results of laboratory and field expe ments to investigate problems of anadromous fish passage at high dams summarized. Studies were made on: pas sage of adult and juvenile fish throu large, medium, and small impoundments design and operation of facilities fo passage of adult fish at dams; mortal ties of juvenile fish passing through turbines and methods of reducing loss collection of juvenile fish from rive streams, and reservoirs; transportati of juvenile fish; and the effect of t changing environment on passage and survival.

U.S. Department of Agriculture, Forest Service.
1975. Making culverts good fish passages. Equip. Dev. Cent. 4 p. Missoula, Mont.

The report covers factors influencing fish passage--velocity, length, resting pools, and water depth. Information is summarized on each topic, with some brief recommendations.

U.S. Department of Agriculture, Forest Service.
1978. Fish/culvert roadway drainage guide. Eng. and Aviat. Manage. Div., Alaska Reg., Juneau. Ser. R 10-42, 125 p.

A guide for engineers, biologists, and hydrologists to aid in solving fish-passage problems, especially for juvenile salmon, trout, and char. Performance ratings of various culvert types, procedures for site selection, methods of determination of the design flow, and hydraulic charts and nomographs are included.

U.S. Department of Agriculture, Forest Service, Alaska Department of Fish and Game, and Department of Natural Resources.
1976. Logging and fish habitat. USDA For. Serv., Reg. 10, 21 p. Juneau, Alaska.

This public information pamphlet is directed mainly to specialists in timber-sale layout, sale administrators, and loggers. Some of the major habitat requirements of salmon and trout are described. Basic practices that will help to protect the habitat are listed. Photos of proper and improper methods and examples of good and poor habitats are included.

41. Watts, F. J.
1974. Design of culvert fishways. Water Resour. Res. Inst., 62 p. Univ. Idaho, Moscow.

Types of fish migration and typical fish-blockage problems associated with culverts are reviewed. Swimming capabilities of fish as a function of species, fish length, and water temperature are discussed. Also reviewed are: (1) hydrologic characteristics of streams and the importance of the timing of fish runs and peak discharge; (2) a procedure for analyzing culverts of corrugated metal pipe and pipe arches for recommended swimming velocities; (3) slot-orifice fishways for box culverts (slot orifice placed perpendicular to the flow and skewed wingwall slot orifice); (4) design aids developed for hydraulic analysis; and (5) instream construction in or near prime fish habitat.

42. Watts, F. J., P. Dass, C. P. Liou, and M. Harrison.
1972. Investigation of culverts and hydraulic structures used for fishways and the enhancement of fish habitat. Water Resour. Res. Inst., Tech. Rep., 7 p. Univ. Idaho, Moscow.

A method for the design of slot-orifice fishways for box culverts was developed. Characteristics for a satisfactory fishway are identified. Graphs for sizing slot-orifice fishways for a given performance capability of a fish are presented. The hydraulics of slot orifices constructed in the face of skewed wingwalls are explained. A table compiled from existing literature lists the swimming capability of various species of fish.

43. Wightman, J. C., and G. D. Taylor.
1976. Salmonid swimming performance in relation to passage through culverts. Fish Habitat Improv. Sect., Fish and Wildl. Branch, Minist. Recreation and Conserv., 50 p. Victoria, B.C.

The authors review literature on swimming performance of fish in culverts to establish standards for culvert design and installation to insure fish passage. Measured swimming abilities of game and nongame fish are explored, as well as factors affecting swimming performance--such as water temperature, dissolved oxygen, and previous exertion. The authors discuss baffles, downstream controls, and multiple installations. Appendixes include recommendations for proper culvert installation, graphs of swimming performances of anadromous fish, and methods for culvert modification.

44. Ziemer, G. L.
1961. Fish transport in waterways. Alaska Dep. Fish and Game, 12 p.

The mechanics of fish passage at and in pipe culvert waterways under highways are given. Illustrations of stylized models demonstrate stress-level patterns of a migrating fish through time compared with normal performance--for example, the work required of a fish to navigate through a culvert where the upstream end head is less than one pipe-diameter. Hydrodynamics are examined for the following: total opposing force on swimming fish; gradient vector; drag force on the fish; weight of fish; angle of inclination of hydraulic gradient; length of fish; mass density of fluid; velocity of fish relative to the water; rate at which fish expends energy; transit time through culvert; length of culvert; and velocity of fish relative to the channel. The report gives a checklist of controlling factors to consider when designing the culvert.

45. Ziemer, G. L.
1965. Culvert design. Alaska Dep
Fish and Game, 2 p.

Standards for design and placement
culverts in salmon streams are presented; a graph shows swimming capability of migrating salmon rela
to the horizontal distance between
resting pools and the velocity of t
water in the culvert.

Anderson, Lynette, and Mason Bryant.
1980. Fish passage at road crossings: An annotated bibliography. USDA For. Serv. Gen. Tech. Rep. PNW-117, 10 p. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

A report of special interest to fishery biologists, resource managers, hydrologists, and road engineers, this bibliography lists publications pertinent to road crossings of salmon and trout streams. Topics include bridge and culvert installation, design criteria, mechanics, hydraulics, and economics, as well as their biological effects.

Keywords: Bibliographies (fish habitat), fish habitat, forest engineering.

The **Forest Service** of the U.S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.

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Ecological Characteristics of Old-Growth Douglas-Fir Forests

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Arthur McKee, Chris Maser, James Sedell, Fred Swanson,
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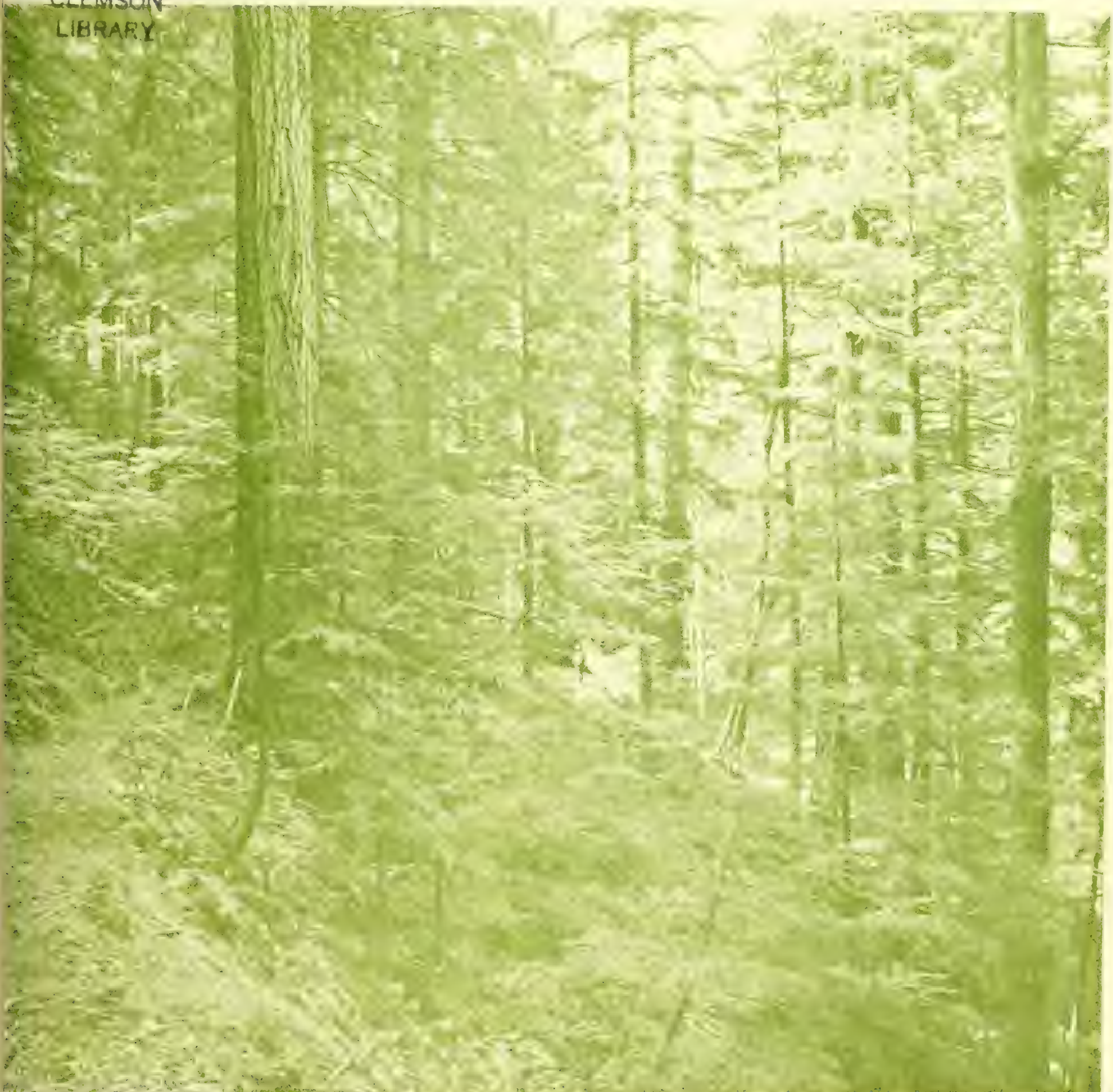

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Summary

The major ecological features of old-growth coniferous forests in the Douglas-fir region are reviewed. Special attention is given to characteristics that distinguish old-growth forests from managed and unmanaged (natural) young stands. The primary exemplary type is 350- to 750-year-old Douglas-fir—western hemlock forest typical of the western slopes of the Cascade Range, but other types and locales are discussed. Management techniques for maintenance of old-growth forests are also considered. Major conclusions are:

1. Approximately 175 to 250 years are required to develop old-growth forests under natural conditions in both Coast and Cascade Ranges. Development of old growth is faster on good sites than on poor sites.

2. Few plant or animal species are solely confined to old-growth forests, although many species—including several vertebrates, saprophytic plants, and epiphytic lichens—find optimum habitats in such forests. Some organisms, however, may require old growth to maintain viable populations. Moreover, there are substantial differences in composition and relative abundance of species between young- and old-growth forests.

. Gross productivity is maintained t high levels in most old-growth tands, but mortality generally alances growth. Thus, the merchantable board-foot volume tends to remain constant for several centuries r gradually decreases because the mount of defect increases. Total rganic matter keeps increasing ecause of accumulated masses of ead tree boles, mostly as down ogs.

. Old-growth forests are highly etentive of nutrients; large amounts re incorporated into living and dead rganic matter. Losses of limiting utrients, such as nitrogen, are low.

5. Nitrogen-fixing epiphytes are abundant in old-growth trees, and bacterial nitrogen fixation appears to be common in the large woody debris characteristic of old-growth forests.

6. Small- to medium-size streams in old-growth forests depend mainly on forest litter for an energy base. These materials are invariably partially utilized before they are exported downstream.

7. The structure of old-growth forest is more heterogenous than that of young forests; coefficients of variation in tree sizes are greater, and understory patchiness is much higher than in young-growth stands.

8. Most of the distinctive features of old-growth forests can be related to four structural features: (1) large, live old-growth trees, (2) large snags, (3) large logs on land, and (4) large logs in streams. The structural features are related over time.

9. A large, old-growth Douglas-fir is individualistic and commonly has an irregularly arranged, large, coarse branch system, and often, a long crown. It is ideal habitat for specialized vertebrates, such as the red tree vole, northern spotted owl, and northern flying squirrel, as well as nitrogen-fixing lichens.

10. Large snags are valuable as habitat for a variety of vertebrates and invertebrates and as a future source of logs.

11. Logs on the forest floor are important habitats for small mammals, including species that disperse spores of mycorrhiza-forming fungi. They also are sites for substantial bacterial nitrogen fixation and are essential as seedbeds for some trees and shrubs.

12. Logs are critical to maintenance of physical and biological stability in headwater streams. Debris dams create stepped stream profiles that dissipate energy otherwise used for transporting sediment and lateral-cutting and downcutting of stream channels. Such dams, with their associated plunge pools and beds of trapped gravels and fine sediments, provide a range of habitats needed to maintain a full array of stream and stream-margin organisms. Logs are an important source of energy, and the bulk of the ntirogen supply of a stream comes from woody debris.

13. Foresters wishing to maintain or create ecosystems with old-growth characteristics can tie management schemes to maintenance or development of the four key structural components—large live, old-growth trees, large snags, and large logs on land and in streams.

14. Watersheds are probably best suited as management units for old-growth ecosystems. A small drainage usually has greater terrestrial habitat variability than occurs in a single stand, as well as a complete stream system. The size of a management unit will vary but probably should be at least 300 acres (120 hectares) to reduce effects of edges and susceptibility to damaging agents, such as wind, as well as to maintain viable populations of some birds and small mammals.

15. Buffer or leave strips along streams are also useful areas to manage as old-growth sites because woody debris is provided to the stream, and the riparian zone, a particularly rich and critical wildlife habitat, is protected. Such buffers, along with roadside strips of old-growth forest, also provide migration routes for wildlife between otherwise isolated patches of mature or old-growth forest.

16. Some ecological aspects of old-growth forests can be maintained by managing for individual attributes; for example, leaving scattered old-growth trees, rotten logs, or snags on cutover lands. The linked nature of these key structural components, as well as the requirements of some organisms for the total environment of an old-growth stand, makes management of entire stands a simpler approach to retention of such ecological features.

Abstract

Franklin, Jerry F., Kermit Cromack, Jr., William Denison, Arthur McKee, Chris Maser, James Sedell, Fred Swanson, and Glen Juday.
1981. Ecological characteristics of old-growth Douglas-fir forests. USDA For. Serv. Gen. Tech. Rep. PNW-118, 48 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Old-growth coniferous forests differ significantly from young-growth forests in species composition, function (rate and paths of energy flow and nutrient and water cycling), and structure. Most differences can be related to four key structural components of old growth: large live trees, large snags, large logs on land, and large logs in streams. Foresters wishing to maintain old-growth forest ecosystems can key management schemes to these structural components.

Keywords: Ecosystems, old-growth stands, stand composition, stand structure, Douglas-fir, *Pseudotsuga menziesii*, western hemlock, *Tsuga heterophylla*.

Contents

ntroduction

)ld-growth forests—forest ecosystems that have developed ver a long period essentially free of atastrophic (including human) isturbance—are in increasingly hort supply. In the Pacific North- vest, coniferous forests dominated y large, old trees occupied large xpanses of the presettlement land- cape, despite periodic episodes of vildfire. These forests represented oth a valuable resource (large olumes of high quality wood) and a indrance to agricultural develop- nent. Consequently, their elimina- on began early and has progressed o the point where, today, most of he remaining old-growth forests are n Federal lands, including the ational Forests.

t current harvest rates, old-growth tands will not be completely cut ver for at least four decades, even n National Forest lands where mber production is a primary ob- ctive. And many tracts of old- owth forest are permanently pro- cted in National Parks, Wilder- ess, Research Natural Areas, and milar reserves. Nevertheless, these serves occupy less than 5 percent the original landscape, and the nd of the unreserved old-growth rests is in sight. The public, scien- ists, and land managers are in- easingly concerned about whether ecies, communities, and functions e in danger of being eliminated. e there unique features, species, important values associated with d-growth forests? Foresters are re- onding to such concerns by con- dering longer forest rotations on me areas or preserving specimen oves within the managed forest ndscape.[1]

The expanded interest in old-growth forests surfaces many unanswered questions. Clearly, an old-growth forest is more than a collection of some large, old trees; but what else characterizes these forests? How are old-growth forests distinguished from natural second-growth forests that follow fire or result from managed stands? Once key attri- butes of old-growth forests are defined, further practical questions remain, such as: What characteris- tics should be sought by foresters attempting to perpetuate or re- create such ecosystems? What size tracts are essential to maintain a viable ecological unit, and what is the best geographic distribution of areas?

A group of scientists and land managers gathered at a work ses- sion sponsored by the USDA Forest Service in February 1977 to address these questions. The objective was to identify the ecological charac- teristics of old-growth coniferous forests and how they differ from young-growth and/or managed for- ests to provide suggestions for management strategies, and to iden- tify areas for future scientific research.

This report represents current know- ledge about the characteristics of an old-growth conifer forest in the Douglas-fir region of the Pacific Northwest. Special attention is directed to management problems, selection of old-growth reserves, development of old-growth stands by long rotations, and perpetuation of attributes of old growth in areas under intensive forest management. Much more research will be neces- sary, however, to provide definitive guidance in such topics as distribu- tion and necessary size of old- growth management areas.

Definitions and Assumptions

Old-growth Douglas-fir—western hemlock forests are the primary ex- ample of old-growth ecosystems in western Oregon and Washington. (Scientific names of trees are listed on page 44.) These forests, generally 350 to 750 years old, are the most common type of old-growth forest, particularly on western slopes of the Cascade Range. They are, in fact, the type of ecosystem commonly associated with the term "old growth," although forests as young as 200 years and as old as 1,000 years are also known as old growth. Other species and types also occur as old growth, such as Sitka spruce—western hemlock forests of coastal Oregon and Washington and the subalpine true fir-hemlock forests found the length of the Cascade Range. These will be com- mented on to the extent that available data permit.

In the strict sense, 350- to 750-year- old forests in the Douglas-fir region are generally not climax forests. Most stands of this age retain a significant component of long-lived Douglas-fir in the dominant tree canopy and will continue to do so for several more centuries. Because Douglas-fir is a subclimax species on most sites, subject to replace- ment by western hemlock and other more tolerant associates, stands of this type are technically in a subclimax condition. The structure and composition of the understory (as opposed to the tree canopy) are thought to be essentially the same as in a climax forest. The point is that old-growth Douglas-fir forests are not climax forests. True climax forests lack the large dominant Douglas-firs that give the forests much of their character and have tree layers of one or two shade- tolerant tree species (for example, western hemlock) which usually do not get as large. Other old-growth forests typically have long-lived pioneer species that attain large sizes, giving them much of their character, but which are generally lost in a climax forest. Examples are noble fir in subalpine environments, Sitka spruce along the coast, and sugar pine in southwestern Oregon.

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[1]s an example, the preferred manage- ent alternative in the draft environ- ental statement for the Hebo Planning it of the Siuslaw National Forest SDA Forest Service Region 6 1977) mmits 6,400 acres (2 560 ha) to intenance of older forest. Under a 0-year rotation, approximately 3,000 res (800 ha) of this would be main- ned in the 200- to 300-year age class.

Coast redwood forests are one type that apparently do retain very large dominant specimens in a true climax condition (Franklin and Dyrness 1973). If Cupressaceae, such as western redcedar and Alaska-cedar, are present, very large dominant trees may remain in stands otherwise dominated by western hemlock or Pacific silver fir for yet another millenium beyond the disappearance of the Douglas-fir; members of this family have extremely long lifespans and some ability to reproduce under closed forest conditions.

In this report, the stream component of an old-growth ecosystem is considered along with the terrestrial component. Stream conditions depend strongly on the nature of associated forests. In fact, streams in old-growth forests contain several of the most distinctive features of these ecosystems.

Attributes of forest ecosystems are composition, function, and structure. Composition refers primarily to the array of plant and animal species present in an ecosystem. We also considered dominance an element of composition; that is, shifts in abundance as well as presence or absence of species. Function refers to how various ecological processes, such as production of organic matter and cycling of nutrients (through pathways and compartments), are accomplished and the rates at which they occur. It is well known that, as ecosystems develop or age, the relative size of various compartments, complexity of pathways, and transfer rates change (Odum 1971). Increased complexity in routing dead organic material (development of a system based on detritus) is one characteristic example of a functional change with succession. We considered types and rates of ecological processes as functional features of an ecosystem. Structure refers to the spatial arrangement of various components of the ecosystem, such as heights of various canopy levels and spacing of trees.

Finally, we define some terms and determine age limits for old-growth forests. It is difficult to define a lower age limit for old growth. The transition from mature to old-growth forest is gradual, and the age limit varies with site conditions (trees take different times to reach comparable size or physiological age on different sites) and with the type of stand (initial density and composition) that develops after the last disturbance. We would expect earlier development of old-growth characteristics on better Douglas-fir sites, in coastal environments, and in understocked stands and delayed development on poor sites, on many (but not all) subalpine environments, and in overstocked stands.

Forests typically begin exhibiting old-growth characteristics at about 175 to 250 years. Forests up to about 75 to 100 years old can generally be considered ecologically young in the Douglas-fir region. This is the period of very rapid growth or "adolescence." Mature forests are those in the period between culmination of maximum growth (peak of the growth curve) and the development of old-growth characteristics; that is, generally between 100 and 200 years. Federal foresters normally select the culmination of mean annual wood increment (end of youth) as the rotation or cutting age in managed forests. Substantial net growth (or net accumulation of live biomass) does continue in the mature forest although at a slower rate than in the young stand.[2] There is typically little net gain or loss of live biomass in most old-growth forests over the long run, barring some catastrophe. This may change in extremely old forests (>750 years), but few examples of such old forests exist, even in the Pacific Northwest.

In this report, we distinguish between natural young-growth forests (such as those that have followed wildfires) and managed young-growth forests. Contrasts are very sharp between natural and managed young growth in several ecological attributes, such as the number of snags and rotten logs. Our concept of managed stands is based on current USDA Forest Service plans of prompt establishment of fully stocked young conifer forests after cutting of natural stands and major efforts to dispose of residue. We assume that such forests will typically have moderate levels of management (for example, thinning) and will have an 80- to 90-year rotation—a somewhat more conservative strategy than is currently practiced on the most intensively managed industrial forest lands in the Pacific Northwest.

We have attempted to contrast the features of old-growth and second-growth forests. Surprisingly, some aspects of younger forests have not yet been studied, so comparable data are not always available. In such cases, we have described the old-growth condition; future research on young growth should provide comparisons. When reading this report or drawing inferences from it, the reader is cautioned to be careful in distinguishing natural second- or young-growth stands from managed young-growth forests in any comparisons with old-growth forests.

[2] Williamson and Price (1971) show some very high rates of growth in stands at or beyond average current rotation ages. Seven plots in unthinned Douglas-fir stands 90 to 150 years of age averaged a net growth of 114 ft^3/acre (690 board feet (fbm) per acre or 8 m^3/ha) per year.

Characteristics of Old-Growth Forests

Figure 1. Old-growth Douglas-fir—western hemlock forest showing diversity of tree sizes and heterogeneity of understory.

Some general attributes of an old-growth forest are immediately apparent to an observer with even a moderate background in natural history (fig. 1). Trees typically vary in species and size; dominant specimens are truly impressive. Some large species differ in color and texture as well as in size. The multilayer canopy produces a heavily filtered light, and the feeling of shade is accentuated by shafts of sunlight on clear days. The understory of shrubs, herbs, and tree seedlings is often moderate and is almost always patchy in distribution and abundance. Numerous logs, often large and in various stages of decay, litter the forest floor, creating some travel routes for wildlife and blocking others. Standing dead trees, snags, and rotted stubs are common, although a visitor gazing toward the ground will often mistake dead trees in early stages of decay for live trees. It is quiet; few birds or mammals are seen or heard except perhaps the melody of a winter wren (*Troglodytes troglodytes*), the faint songs of golden-crowned kinglets (*Regulus satrapa*) in the tree canopies, or a chickaree (*Tamiasciurus douglasi*).

Figure 2. Small streams within old-growth forests depend heavily on terrestrial vegetation for energy and physical integrity.

Small to moderate size streams flowing through old growth (fig. 2) are shaded, often completely shielded from the sun by the canopies of adjacent trees. The smallest streams may be choked with organic debris; as size and volume of streams increase, clear, cool water runs through gravel beds behind old log dams and spills into plunge pools. Organic debris—for example, leaves, needles, twigs, bud scales—floats on the surface and accumulates in backwaters.

Some of these impressions represent important, distinctive aspects of an old-growth forest ecosystem that we will discuss as composition, function, and structure. Structural aspects of old-growth forests are the major unifying element since the peculiar compositional and functional features are mainly related to the distinctive structure of old growth. We discuss composition and function first, however, so that these aspects are not completely overshadowed by that of old-growth structure. We discuss composition and function again in the sections on habitat and cycling roles of live old-growth trees, standing dead trees or snags, logs on land, and logs in streams.

Composition

Old-growth forests obviously differ in composition from young stands. Ecological succession produces changes in the array of plant and animal species as well as in their relative abundance. Hence, there is a change from pure or nearly pure young forests of Douglas-fir to mixtures of old-growth Douglas-fir, western hemlock, western redcedar, and other species. Thomas et al. (1979c) outlined the changes in animal species associated with plant community successional stages in the Blue Mountains of eastern Oregon. These principles apply equally to Douglas-fir–western hemlock forests, as shown by Gashwiler (1970) and others. The most sterile successional stage, in diversity of both plant and animal species, is a dense, rapidly growing young conifer forest (Edgerton and Thomas 1978, Long 1977, Meslow 1978).

Few vascular plants appear confined to old-growth ecosystems in the Douglas-fir region. Lists of species from old-growth Douglas-fir–western hemlock stands in the H.J. Andrews Experimental Forest (Dyrness et al. 1974) show none that are confined to old-growth forests.

Some vascular plants do find optimum habitat (or most frequently—suitable environments) in old-growth Douglas-fir ecosystems. These are often saprophytic[3] plants belonging to the orchid and heather families—for example, phantom orchids (*Cephalanthera austinae*), pinesap (*Monotropa hypopitys* L.), woodland pinedrops (*Pterospora andromeda* Nutt.), and candystick (*Allotropa virgata*)—which favor heavily shaded environments rich in organic debris. Again, these vascular plants are not confined to old-growth ecosystems but often find suitable environments there.

[3] Saprophytic plants obtain all or part of their energy from decomposition of dead organic materials rather than by photosynthesis. Most vascular plants characterized as saprophytic have fungal associates essential to their survival (Furman and Trappe 1971).

The percent of each type of food available to microbes and invertebrates in small streams under old growth is presented in table 4. Woody material constitutes 50 to 70 percent of the total organic material, including very fine particles derived almost exclusively from bole wood; these data do not include bole wood, however, because it would completely overwhelm the other categories in table 4.

Invertebrates in the smallest streams flowing through old-growth forests have evolved to gouge, shred, and scrape wood and leaves and to gather fine organic particles. These first- and second-order streams are loaded with wood and have many wood-gouging beetle larvae and leaf-shredding stoneflies and snails. The small particles of organic material trapped by the large wood are gathered and fed on by a benthic copepod. These streams are noted for their uniqueness in that each is predominantly a beetle-stonefly-copepod-miniature snail invertebrate community (fig. A), not for an abundance of invertebrate populations.

Third- to fourth-order streams are generally richer in kinds, numbers, and biomass of organisms than are smaller streams—including a rich variety of insects and a continuous population of vertebrates, such as cutthroat trout (*Salmo clarki*), tailed frog, and Pacific giant salamander. The richness and abundance are due, in part, to the increased importance of algae as a source of energy.

The green plants or primary producers in streams also vary widely by size of stream. In first- and second-order streams, moss cover is generally greater than 20 percent of the stream area and is located primarily on wood, bedrock, and boulders. The moss community generally occupies 5 percent or less of the stream area in third- and fourth-order streams—mostly on wood, bedrock, and large boulders. The algal community—primarily diatoms, green algae, and a few blue-green algae—is well developed and widely spread throughout larger streams. Small streams have a sparse diatomaceous flora and a patchy blue-green algal community which is intimately associated with the mosses.

Large woody debris is responsible for two types of habitat within each stream—wood and wood-created environments, such as depositional pools. Each of these habitats, as well as those not related to wood (mineral sediments in streambed formations not created by wood or bedrock), has a different faunal composition. Relative proportions of wood-related and other habitats vary markedly with size of streams. In the smallest streams, 50 percent or more of the area may be occupied by wood and wood-related habitats compared with 25 percent for third- and fourth-order streams.

Coarse woody debris also functions as a major source of N. Although the content of N in wood is small, large amounts of N are fixed in and on woody debris. In one small watershed in the western Oregon Cascade Range, input of N in wood or fixed in wood accounts for 52 percent of the total input of N to the stream, not counting N in woody material over 4 inches (10 cm) in diameter (table 5).

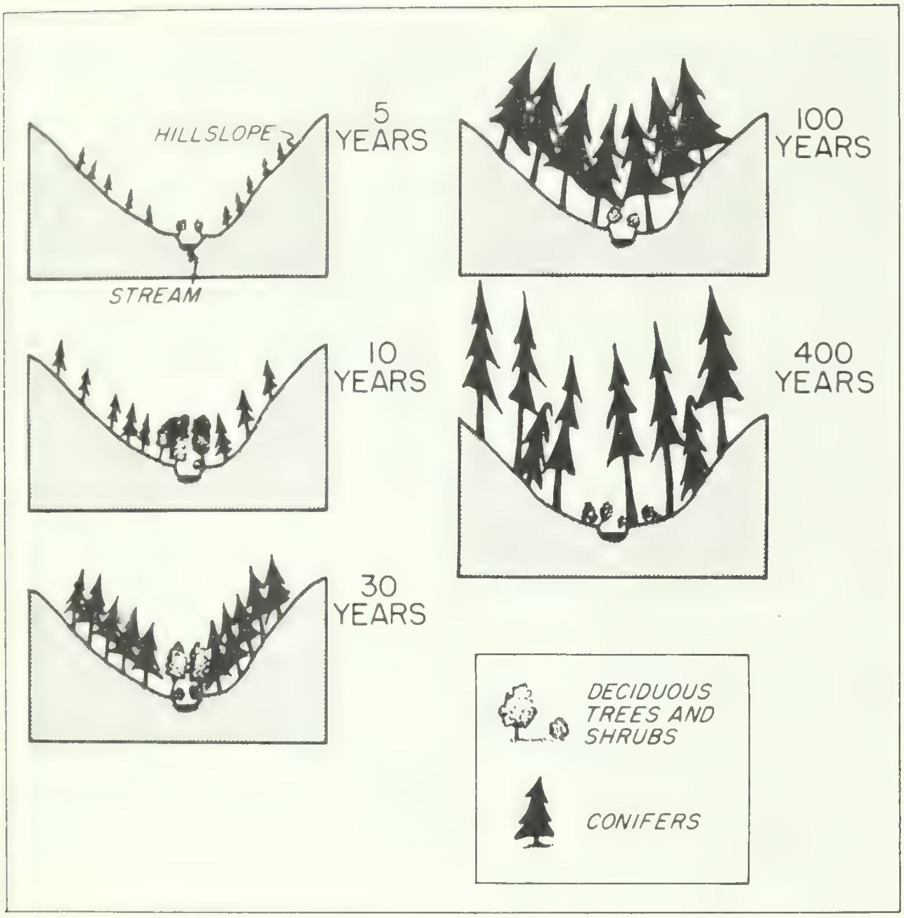

Figure 5. Hypothetical changes in the riparian zone through succession in Douglas-fir—western hemlock forests (Swanson et al. 1981b; from Analysis of Coniferous Forest Ecosystems in the Western United States *US/IBP Synthesis Series, V. 14, edited by R. L. Edmunds. Copyright © 1981 by Dowden, Hutchinson & Ross, Inc., Stroudsburg, Pa. Reprinted by permission of the publisher.)*

The environment of streams dominated by forest varies with stand age in response to changes in structure of streamside vegetation as it develops through time. A hypothetical succession of streamside vegetation is shown in figure 5. In small streams in the western Cascade Range, dense riparian stands of deciduous shrubs and small trees develop in one to two decades. Beyond that point in development, upslope conifers begin to overtop the deciduous streamside vegetation. Stands 50 to several hundred years old have a dense canopy of deciduous trees with little understory vegetation. Older stands have a multilayered structure, and more light penetrates to streams.

These variations in structure of the stand through time are reflected by shifts in both energy base and habitat in streams up to about fourth order. Although little is known about actual productivity of streams through succeeding stand structures, algae are known to be a dominant source of energy before the canopy closes; they continue to be an important contributor in small to intermediate streams as long as there is a hardwood canopy cover. When the stream is completely enclosed by a conifer canopy, the ecosystem shifts to a food base of conifer litter which is of lower quality than algae. The more open canopy of old growth provides greater diversity of nutrient inputs, including algae and litter of herbs, shrubs, hardwoods, and conifers.

Murphy (1979) measured populations of vertebrate and invertebrate predators, including salamanders in streams in recent clearcuts (less than 10 years old), in 20- to 30-year-old, second-growth stands, and in old-growth forests. He found that numbers and biomass of predators in the total stream, particularly cutthroat trout, were highest in recent clearcuts, lowest in second growth, and intermediate in old growth. Aho (1976), studying cutthroat trout, and

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ı summary, old-growth forests ominate both the composition and ıe function of associated streams. errestrial litter is the primary source of energy and nutrients. Woody debris also functions as a major site for fixation of N and as habitat for a broad array of organisms. Logs are also the structural key to the physical and biological stability of a stream. In undisturbed forest, streams are highly retentive of organic materials and nutrients; little escapes without being at least partially processed (consumed and decomposed). Exported material provides downstream reaches with prepared food resources.

The large diameters and heights of the old-growth trees are the most striking structural attributes of these forests. Heterogeneity in diameter and spacing contributes, however, to the variety in an old-growth forest. The pioneers—predominantly Douglas-fir—continue to enlarge in diameter and height over time, while natural thinning reduces their numbers (table 6 and fig. 6). Shade-tolerant species, such as western hemlock, invade the stand and provide smaller trees.

able 6—Density of all trees and Douglas-fir, mean d.b.h. of Douglas-fir, and stand basal area in age sequence of ld-growth Douglas-fir–western hemlock stands in the Cascade Range

Forest	Stands sampled	Density[1]				Mean d.b.h., Douglas-fir		Stand basal area	
		All trees		Douglas-fir					
Years	Number	Number per acre	Number per hectare	Number per acre	Number per hectare	Inches	Centimeters	Square feet per acre	Square meters per hectare
250	3	156	389	50	124	32	81	444	83
250[2]	9	NA	NA	52	130	NA	NA	NA	NA
430[2]	7	NA	NA	31	78	NA	NA	NA	NA
450	7	163	407	24	60	47	119	444	102
850	3	222	556	3	8	71	180	362	83

A = not available.
[1] Trees>2-inch (5-cm) d.b.h.
[2] From Boyce and Bruce Wagg (1953).

Tree density in age series of stands

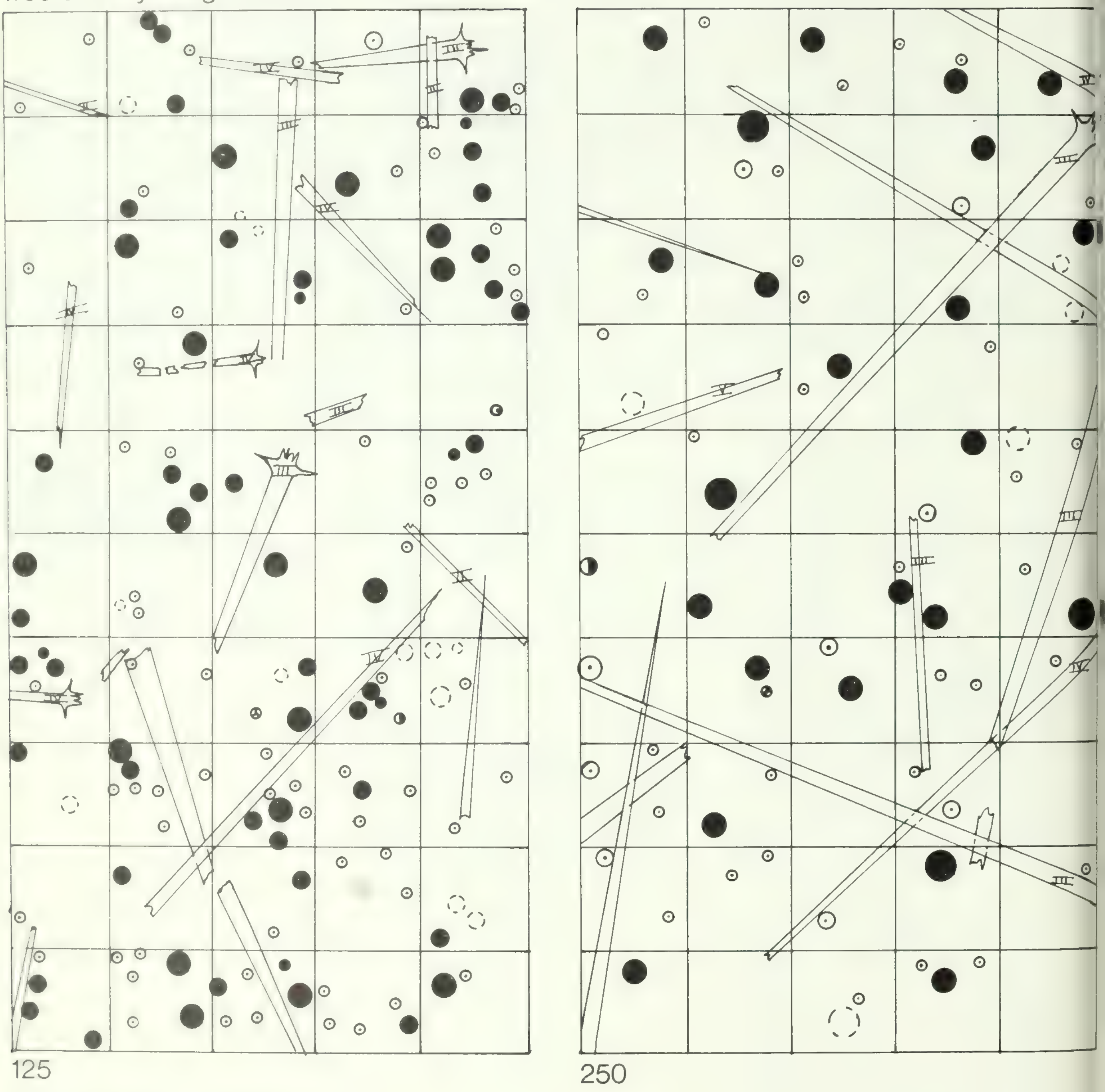
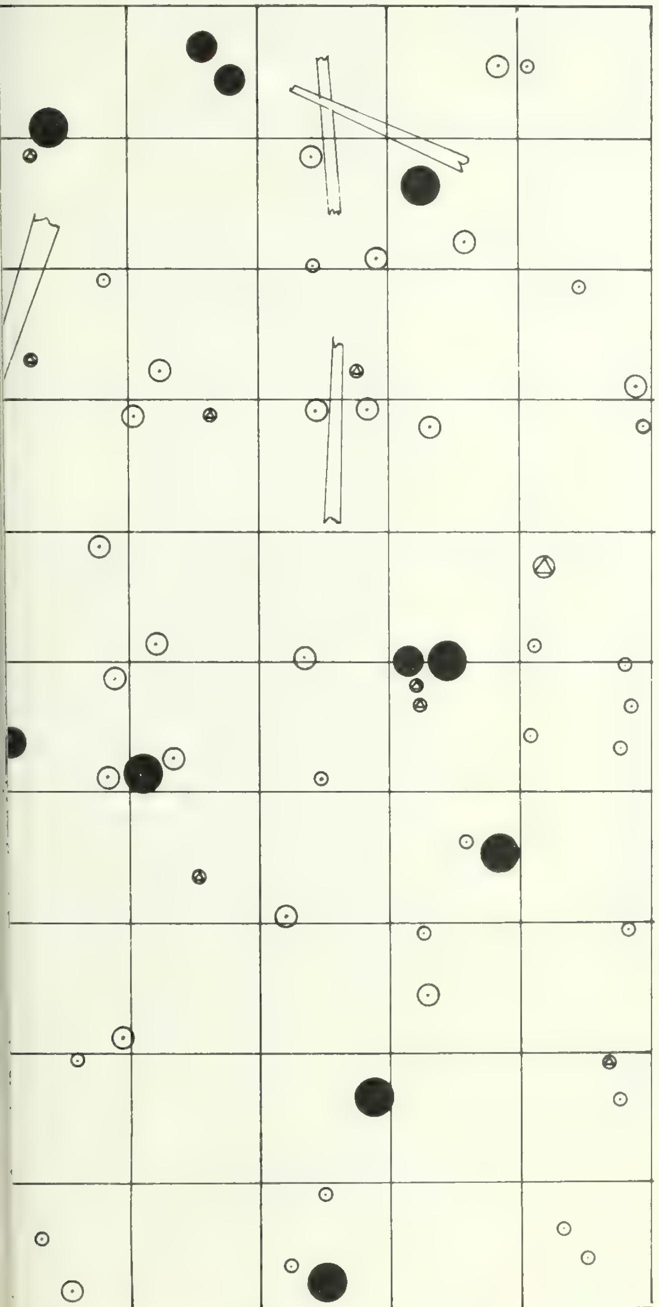


Figure 6. Stem maps of forest stands approximately 125, 250, 450, and 1,000 years of age, suggesting the increased range of tree sizes, reduced densities of Douglas-fir, and shift to shade-tolerant tree associates related to aging of the forest (all live trees greater than 2-inch (5-cm) d.b.h.).

Tree density in age series of stands



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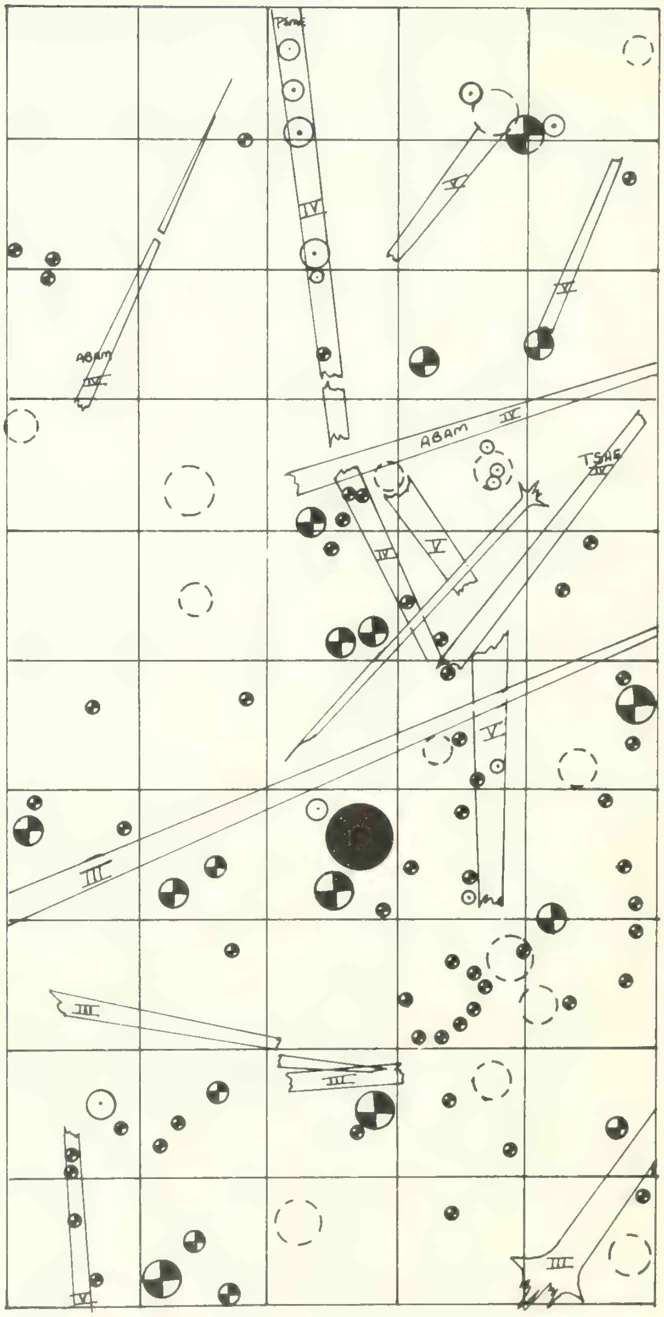


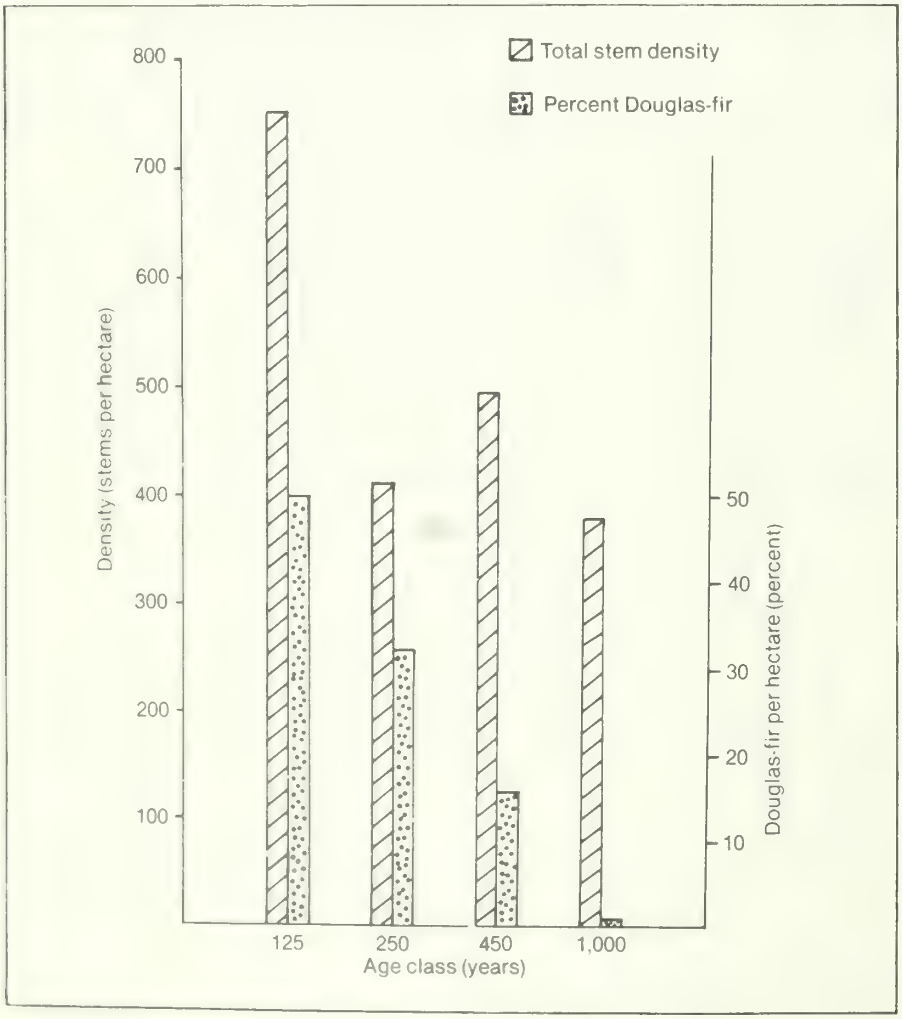
1,000

pecies code:
Pseudotsuga menziesii
Tsuga heterophylla
Abies amabilis
Thuja plicata
Taxus brevifolia

Stem size class (centimeters):
0-25
26-50
51-100
100 +
Standing dead
Logs

Table 7—Mean diameters and coefficients of variation for all trees in excess of 12-centimeter (5-inch) d.b.h. for 7 young-growth stands and 7 old-growth stands on a wide variety of sites in the central Oregon Cascade Range

	Young growth				Old growth		
	Mean diameter		Coefficient of variation		Mean diameter		Coefficient of variation
	Inches	Centimeters	Percent		Inches	Centimeters	Percent
	11.5	28.7	77		10.8	27.0	131
	12.5	31.3	80		12.3	30.8	112
	13.3	33.3	84		14.4	36.1	100
	13.6	34.0	69		15.8	39.5	91
	16.9	42.2	48		17.4	43.5	114
	20.8	51.9	53		21.7	54.2	92
	25.7	64.2	39		29.2	73.1	61
Overall mean	16.3	40.8	64	Overall mean	17.4	43.5	100



Comparison of old-growth stands (450-year) with young-growth stands (125-year) in the Cascade Range of Oregon shows mean diameter of all trees over 12-inch (5-cm) d.b.h. to be close (table 7). The range of diameters is much greater in the old-growth stands, however, and this is reflected in the larger coefficients of variation (table 7). Total tree density (number of stems >2-inch d.b.h./acre or 5-cm/ha) does not appear to change much after a stand reaches 250 years of age (table 6 and fig. 7). Texture of bark changes with age and size, which, with the associated variation in diameter, undoubtedly reinforces the impression of greater heterogeneity in old growth.

There are few data to support the intuitive prediction that spatial heterogeneity of old-growth forests is greater than that of young growth. Moreover, variation in original stocking levels and site productivity from site to site would obscure any pattern in spacing. We tried to reduce some of this variation by pairing three young-growth and old-growth stands on the same habitat types in the Cascade Range. An analysis of distance to nearest tree was performed on the paired stands and on old-growth stands in the Coast Ranges of Oregon. Mean distance to the nearest tree and coefficients of variation in stands in the Cascade Range are somewhat greater in old-growth forests than in young growth (table 8). Because of unequal size of samples and their small numbers, the differences are not statistically significant at even the 10-percent level. The small size of the sample may also be obscuring trends. Mean spacing is significantly greater in stands of the Coast Ranges than in the Cascade Range (5-percent level), however, and the coefficients of variation tend to be larger (table 8).

Figure 7. Densities of all trees and Douglas-fir for stands illustrated in figure 6, showing the relatively constant level of density of all trees greater than 2-inch (5-cm) d.b.h. and declining densities of Douglas-fir.

Another way to examine diversity is to plot histograms of numbers of trees in distance to nearest tree classes for the stands (fig. 8). Distributions are skewed much more toward smaller distances to nearest tree in the young-growth stands than in the old growth.

A commonly used index of diversity H' or the Shannon-Weaver index) was calculated for the stands shown n figure 8 from the histogram data. Higher values of this index indicate greater diversity—the young-growth stands have H' values of 2.037 and 2.212; old-growth stands, 2.332 and 2.443.

Conclusive demonstration of trends toward increased spatial heterogeneity in old-growth forests will require a much larger number of samples along a chronosequence of Douglas-fir stands, as well as in other coniferous forest types.

Diversification of tree structure may begin early. Many 90- to 130-year-old stands begin to show greater ranges n size of trees and a multilayered canopy. Time for development can also vary substantially with site conditions; stands on moist, productive sites develop a wider range of sizes earlier than do stands on dry, less productive sites. The broad range of sizes and varied canopy (as opposed to the monolayer of Douglas-fir canopies in young-growth stands) do not generally become well developed, however, until stands reach 200 to 250 years of age.

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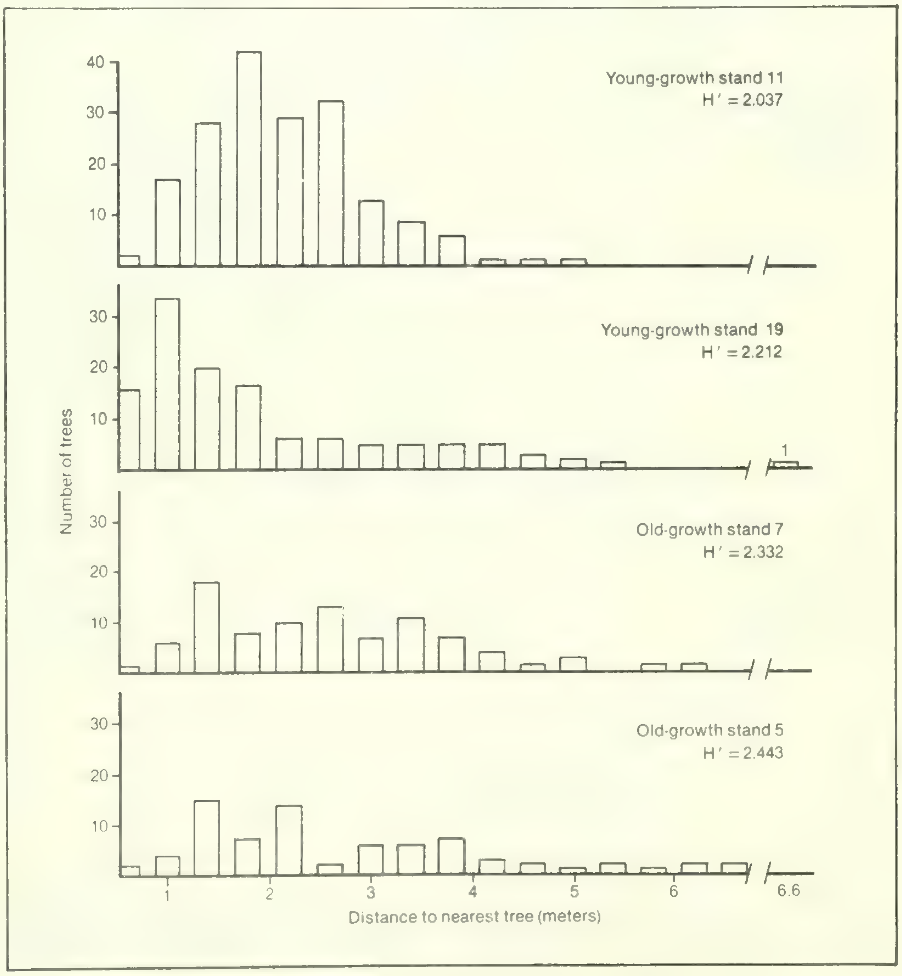
Location	Young growth (125 years)			Old growth (450 years)		
	Mean distance		Coefficient of variation	Mean distance		Coefficient of variation
	Feet	Meters	Percent	Feet	Meters	Percent
Cascade Range	7.00	2.12	37	9.14	2.77	53
	6.30	1.91	67	8.58	2.60	46
	9.24	2.80	49	9.47	2.87	45
Coast Ranges				9.14	2.77	53
				7.00	2.12	63
				9.11	2.76	55
				7.19	2.18	57
				10.56	3.20	65
				10.43	3.16	59
				10.00	3.03	58



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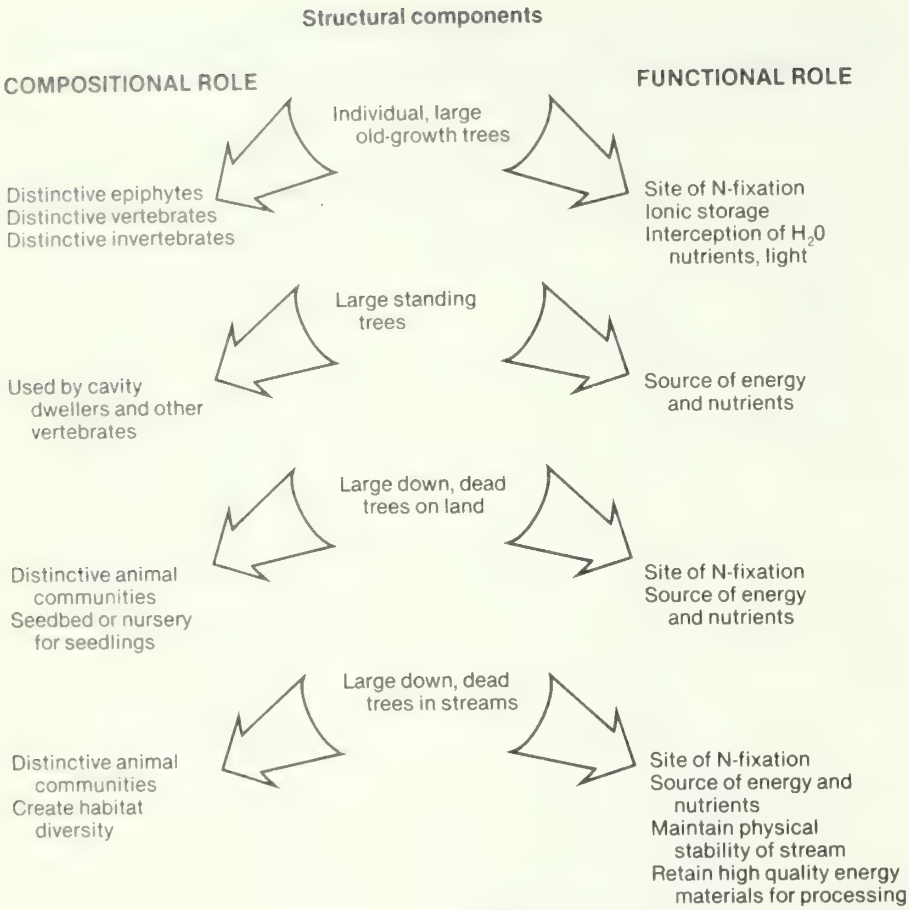
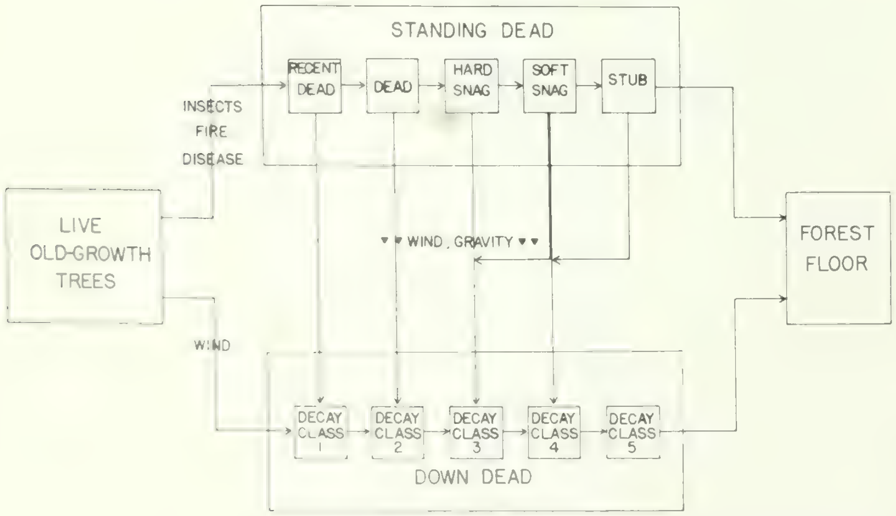


Figure 9. Most of the special habitat and ecosystem functions of old-growth conifer forests can be related to four structural components.



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A phenomenon related to diversification of stand structure is the development of greater patchiness in understory tree seedlings, shrubs, and herbs. Many young stands have relatively uniform understories—whether extremely depauperate, as in very dense stands, or with continuous cover of some dominant understory species, such as salal or swordfern. Homogeneity in the understory vegetation and forest floor gradually disappears as a stand develops. Many factors are responsible—shifting patterns of openings and heavily shaded areas and provision of new substrate, such as windthrown tree trunks and root wads. Understory patchiness seems characteristic of old growth in other forest types (coastal and subalpine), as well as Douglas-fir stands.

Three structural components (or four, counting logs on both land and in streams) are of overwhelming importance in an old-growth forest. These are the individual, live, old-growth trees; the large, standing, dead trees or snags; and the large, dead, down trunks or logs. Logs are at least as important (and possibly more so) to the stream component of the ecosystem as they are to the terrestrial component. It is these structural features that are, in large measure, unique to an old-growth forest ecosystem, setting it apart from young growth and, especially, managed stands. Furthermore, most of the unique, or at least distinctive, compositional and functional features of old-growth forests can be related to these structural features (fig. 9); that is, these structural components make possible much of the uniqueness of the old-growth forest in terms of flora and fauna (composition) and the way in which energy and nutrients are cycled (function).

The percent of each type of food available to microbes and invertebrates in small streams under old growth is presented in table 4. Woody material constitutes 50 to 70 percent of the total organic material, including very fine particles derived almost exclusively from bole wood; these data do not include bole wood, however, because it would completely overwhelm the other categories in table 4.

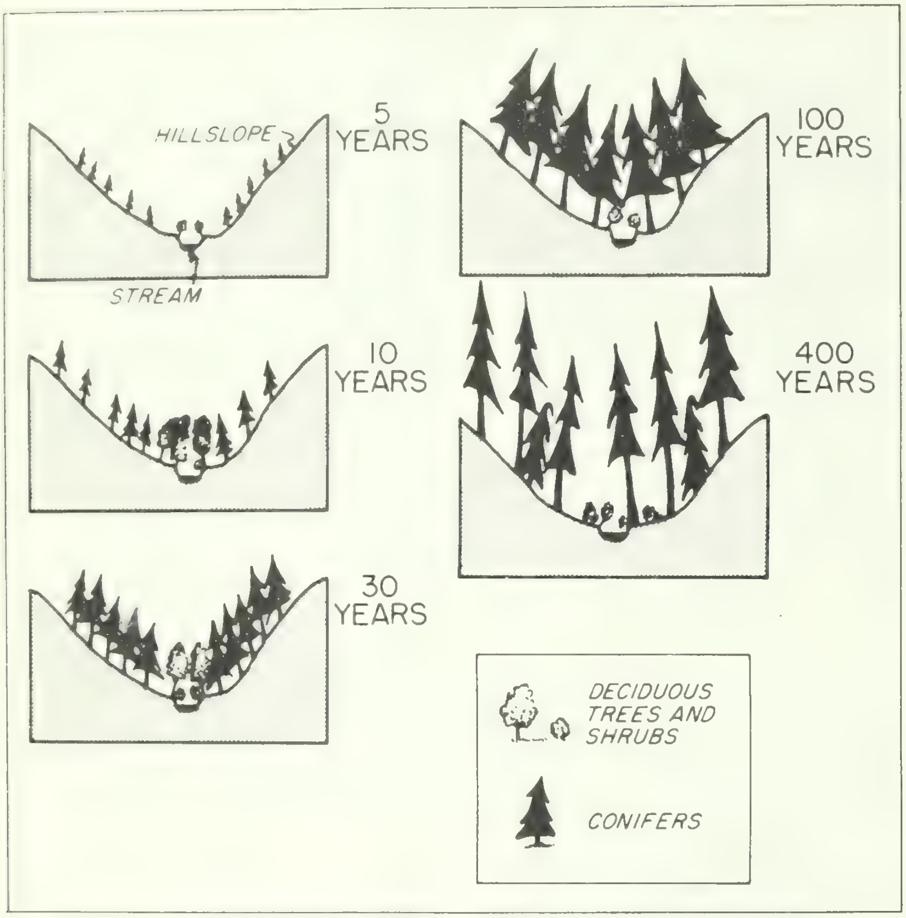
nvertebrates in the smallest streams flowing through old-growth orests have evolved to gouge, shred, and scrape wood and leaves and to gather fine organic particles. These first- and second-order streams are loaded with wood and have many wood-gouging beetle larvae and leaf-shredding stoneflies and snails. The small particles of organic material trapped by the arge wood are gathered and fed on by a benthic copepod. These streams are noted for their uniqueness in that each is predominantly a beetle-stonefly-copepod-miniature snail invertebrate community (fig. A), not for an abundance of invertebrate populations.

hird- to fourth-order streams are enerally richer in kinds, numbers, nd biomass of organisms than are maller streams—including a rich ariety of insects and a continuous opulation of vertebrates, such as utthroat trout (*Salmo clarki*), tailed rog, and Pacific giant salamander. he richness and abundance are ue, in part, to the increased importance of algae as a source of nergy.

The green plants or primary producers in streams also vary widely by size of stream. In first- and second-order streams, moss cover is generally greater than 20 percent of the stream area and is located primarily on wood, bedrock, and boulders. The moss community generally occupies 5 percent or less of the stream area in third- and fourth-order streams—mostly on wood, bedrock, and large boulders. The algal community—primarily diatoms, green algae, and a few blue-green algae—is well developed and widely spread throughout larger streams. Small streams have a sparse diatomaceous flora and a patchy blue-green algal community which is intimately associated with the mosses.

Large woody debris is responsible for two types of habitat within each stream—wood and wood-created environments, such as depositional pools. Each of these habitats, as well as those not related to wood (mineral sediments in streambed formations not created by wood or bedrock), has a different faunal composition. Relative proportions of wood-related and other habitats vary markedly with size of streams. In the smallest streams, 50 percent or more of the area may be occupied by wood and wood-related habitats compared with 25 percent for third- and fourth-order streams.

Coarse woody debris also functions as a major source of N. Although the content of N in wood is small, large amounts of N are fixed in and on woody debris. In one small watershed in the western Oregon Cascade Range, input of N in wood or fixed in wood accounts for 52 percent of the total input of N to the stream, not counting N in woody material over 4 inches (10 cm) in diameter (table 5).



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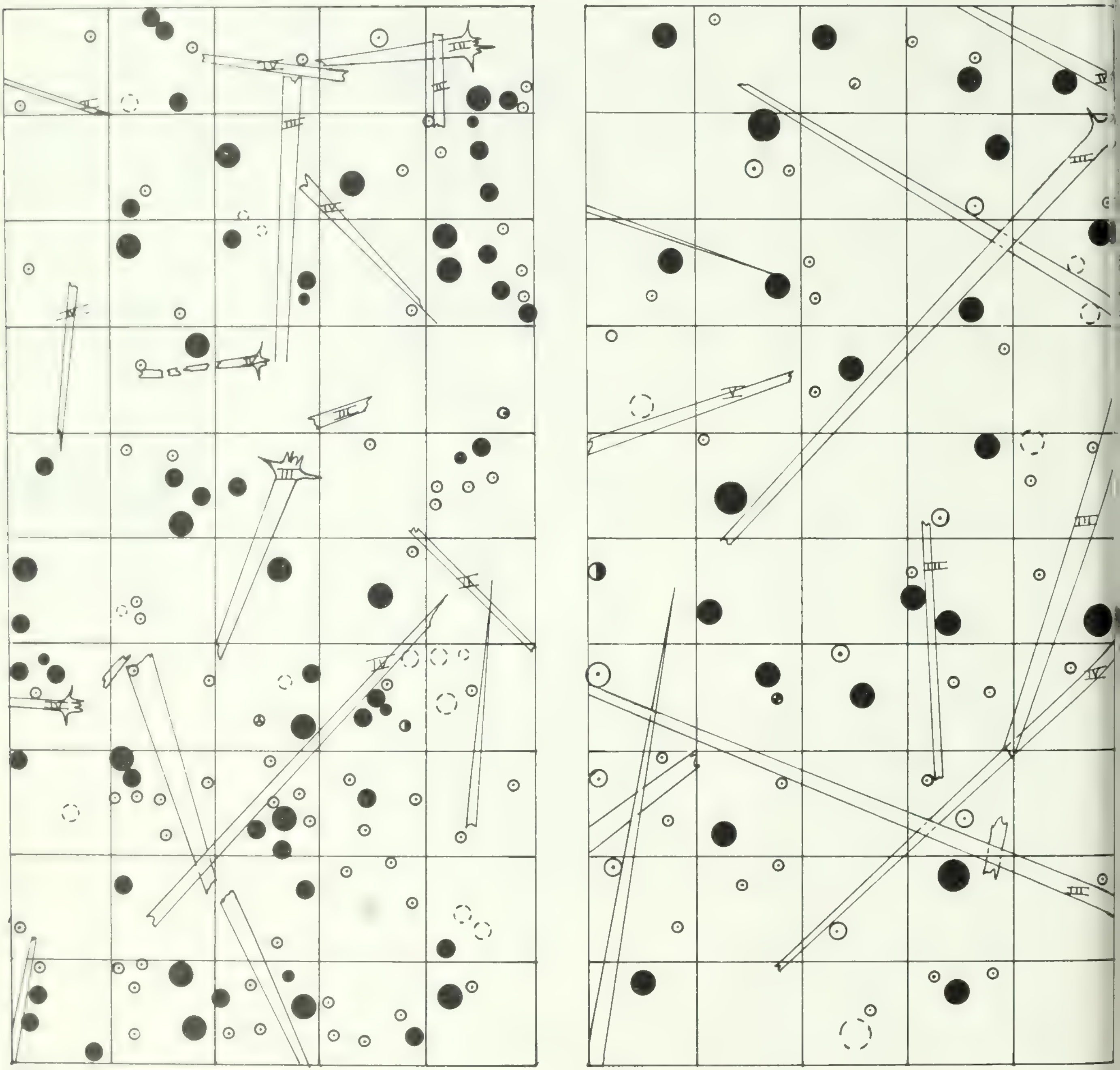

125

250

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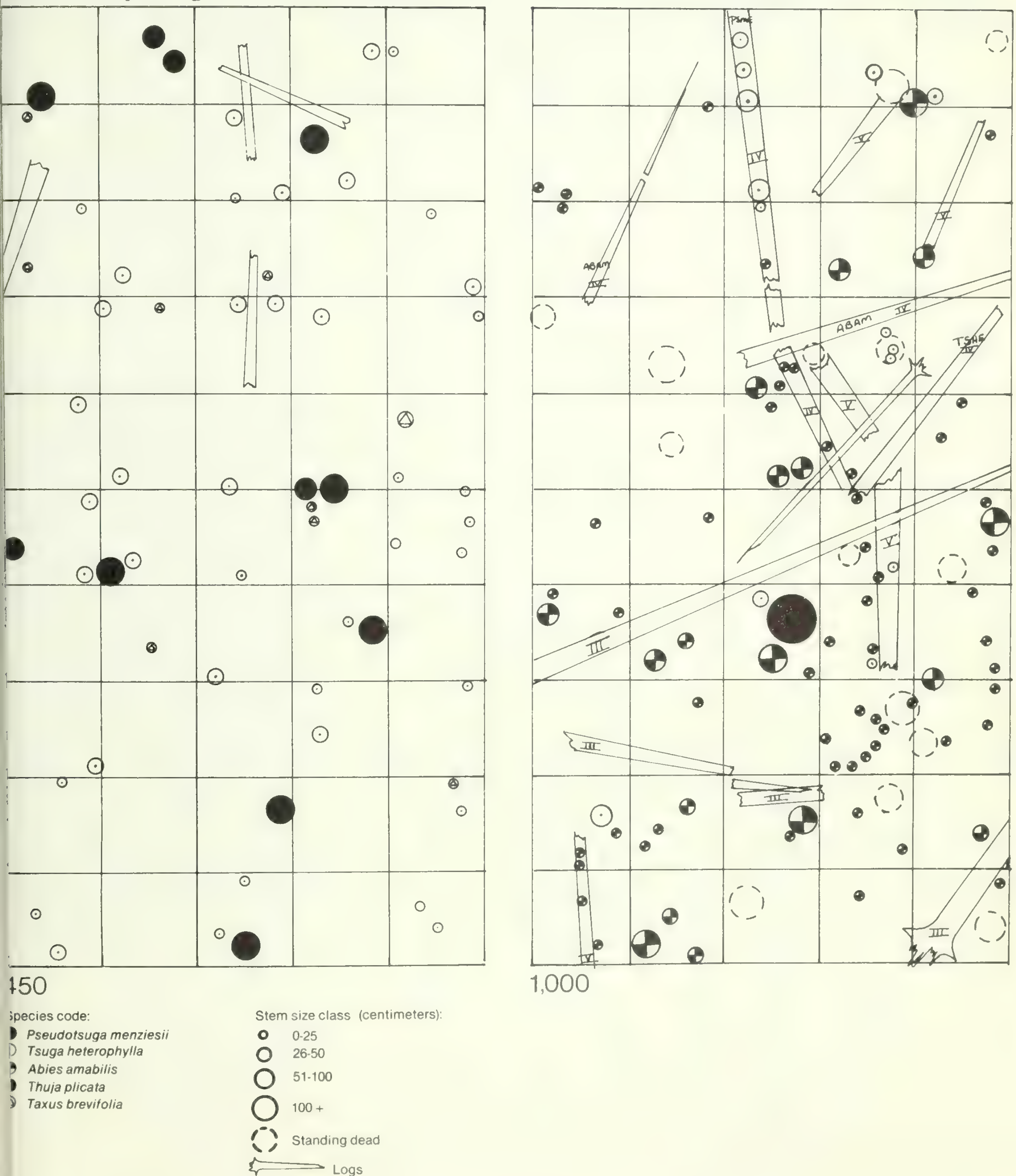

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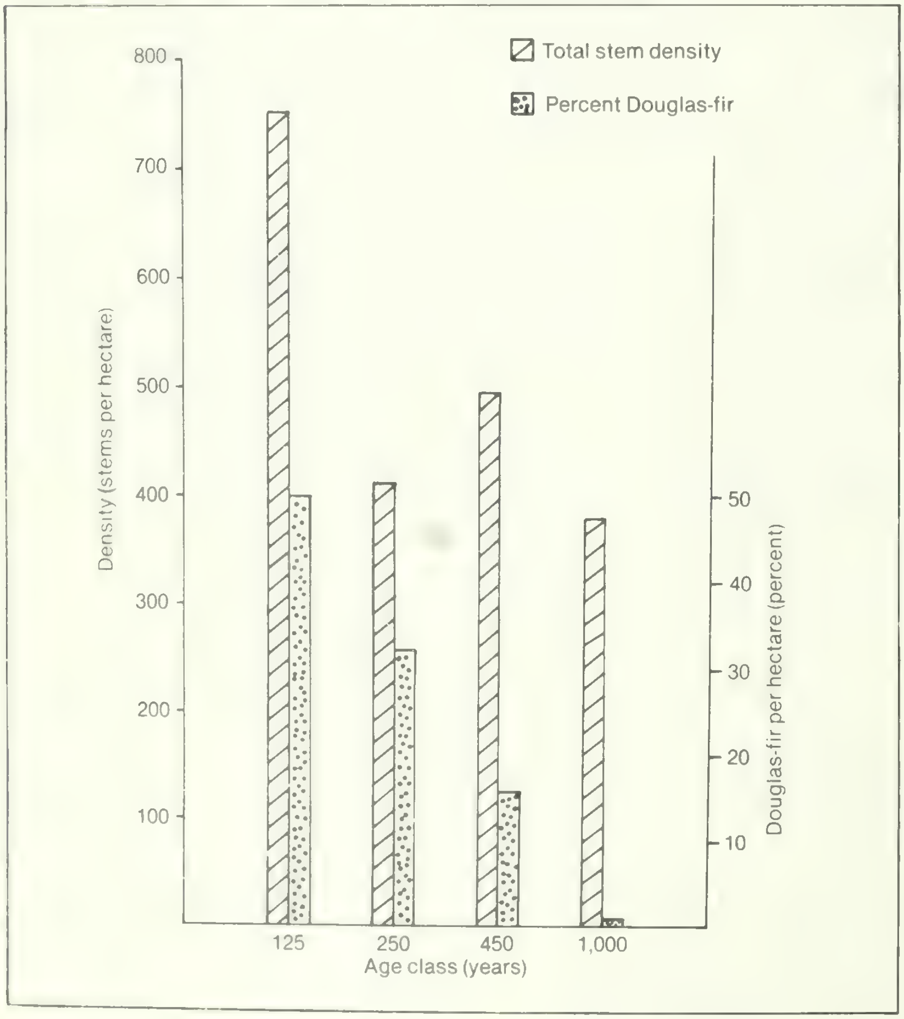

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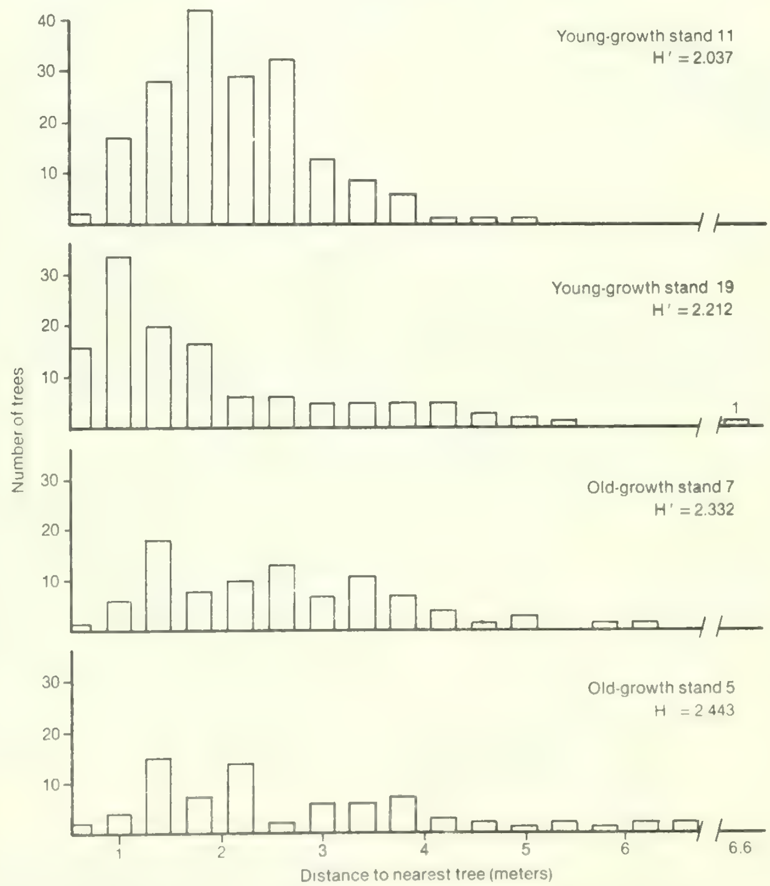

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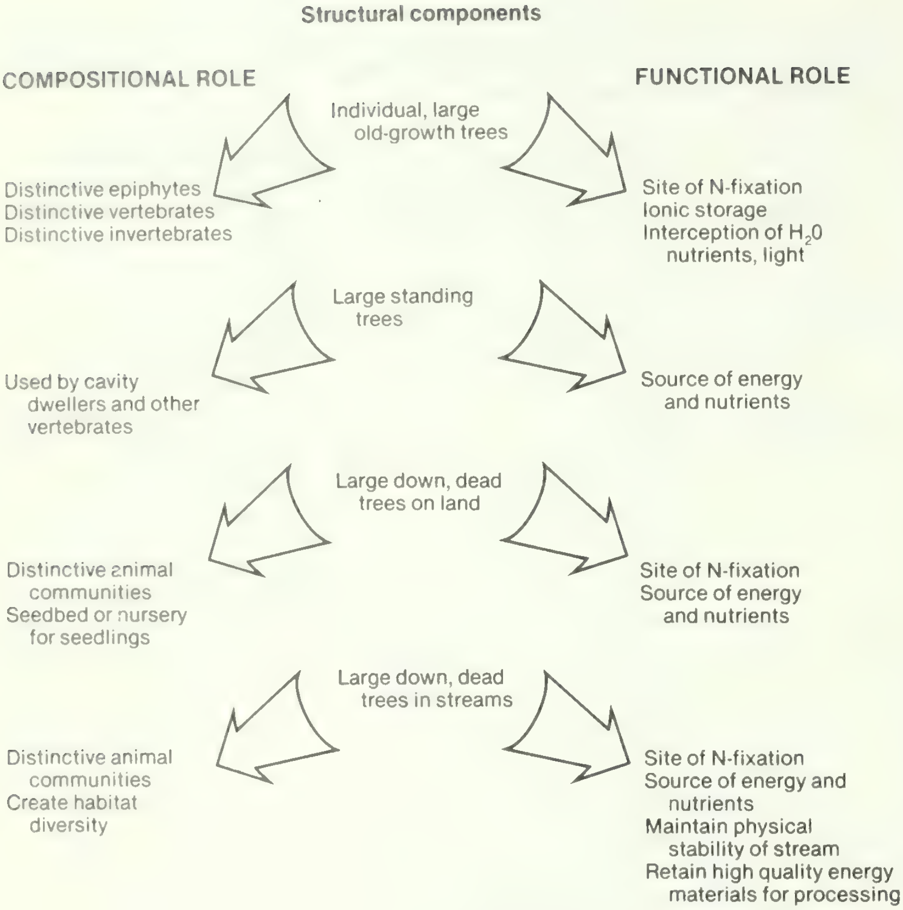

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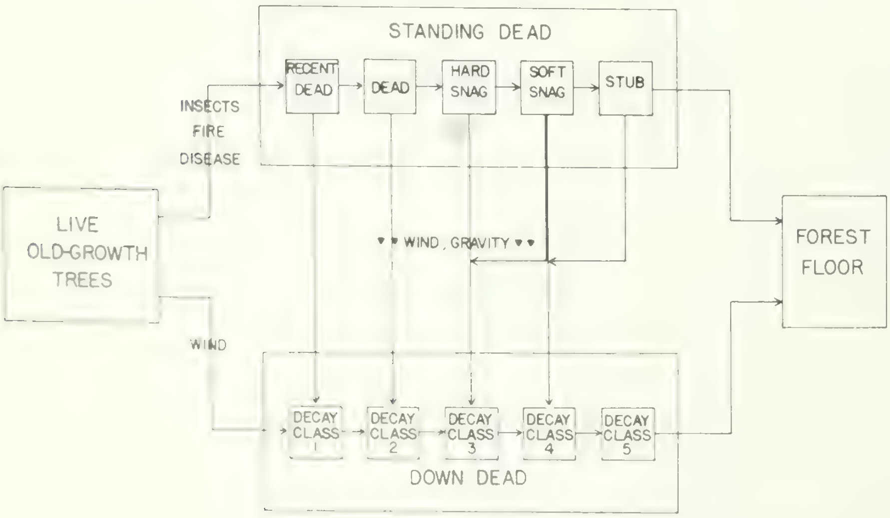

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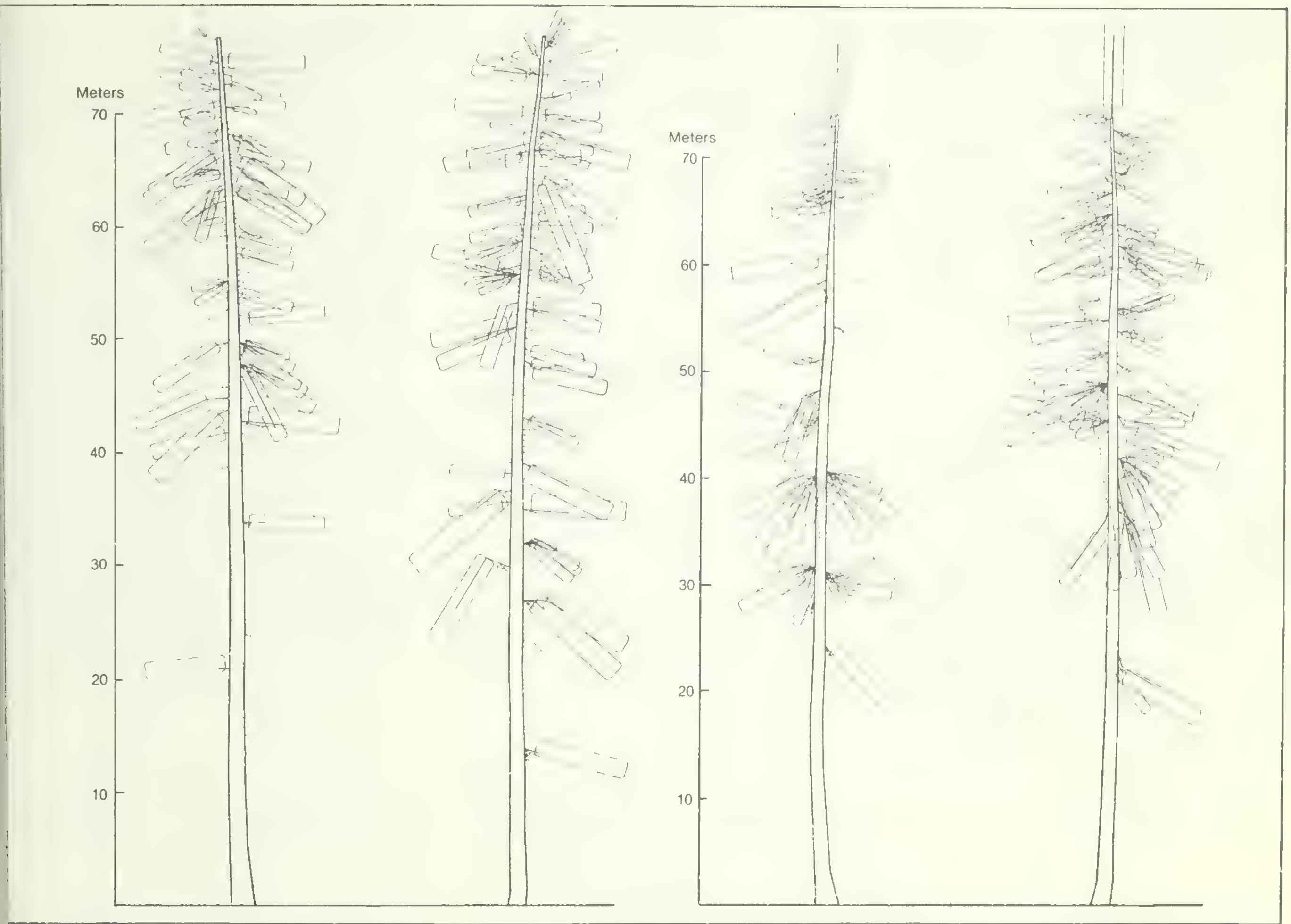
A phenomenon related to diversification of stand structure is the development of greater patchiness in understory tree seedlings, shrubs, and herbs. Many young stands have relatively uniform understories—whether extremely depauperate, as in very dense stands, or with continuous cover of some dominant understory species, such as salal or swordfern. Homogeneity in the understory vegetation and forest floor gradually disappears as a stand develops. Many factors are responsible—shifting patterns of openings and heavily shaded areas and provision of new substrate, such as windthrown tree trunks and root wads. Understory patchiness seems characteristic of old growth in other forest types (coastal and subalpine), as well as Douglas-fir stands.

Three structural components (or four, counting logs on both land and in streams) are of overwhelming importance in an old-growth forest. These are the individual, live, old-growth trees; the large, standing, dead trees or snags; and the large, dead, down trunks or logs. Logs are at least as important (and possibly more so) to the stream component of the ecosystem as they are to the terrestrial component. It is these structural features that are, in large measure, unique to an old-growth forest ecosystem, setting it apart from young growth and, especially, managed stands. Furthermore, most of the unique, or at least distinctive, compositional and functional features of old-growth forests can be related to these structural features (fig. 9); that is, these structural components make possible much of the uniqueness of the old-growth forest in terms of flora and fauna (composition) and the way in which energy and nutrients are cycled (function).



is important to recognize that the our structural components are related (fig. 10). The dead organic tructures—large snags and logs—re derived from the live old-growth ees. The tree thus plays a progression of roles from the time it is live through its transformation to n unrecognizable component of the orest floor.

ive Old-Growth Trees. The most onspicuous of the four key structural components is probably the ve, old-growth Douglas-fir trees. hese trees are large; though size aries with site conditions and age, ameters of 3 to 6 feet (1 to 2 m) nd heights of 165 to 295 feet (50 to 0 m) are typical. They are highly individualistic, much less uniform an trees in a 50- to 150-year-old and. Each has been shaped over the centuries by its genetic heritage, site conditions, competition with nearby trees, and the effects of storms, diseases, insects, and, possibly, soil mass movement.

The large, deep, irregular crown, characteristic of many old-growth Douglas-fir trees, is as ecologically important as the massive trunk (fig. 11). A 450-year-old tree typically has the overall shape of a bottle brush (albeit one with many missing bristles), with a cylindrical crown beginning 65 to 130 feet (20 to 40 m) above the ground and composed of

Figure 11. Schematic profiles of two old-growth Douglas-fir trees illustrating their individualistic nature and deep asymmetric crowns; several fan-shaped branch clusters are identifiable on the lower bole of both trees (diagrams courtesy W. Denison).

Figure 12. Many lower branches on old-growth Douglas-firs are large, horizontally flattened, fan-shaped arrays arising from the stub of an older branch; these provide extensive horizontal surfaces (photo courtesy W. Denison).

slender branches up to 6-inch (15-cm) diameter.[7] Branches are irregularly scattered through the lower two-thirds of the canopy; often there are gaps of many meters on one side of a tree (fig. 11). Many lower branches are horizontally flattened, fan-shaped arrays arising from the stub of an older branch and showing evidence of repeated breakage (fig. 12). Such massive irregular branch systems may be on one side of the trunk, but their folliced parts can spread out to surround over three-quarters of the circumference of the trunk. Upper surfaces of large branches are covered by organic "soil" (several centimeters thick), which is perched on the branches and supports entire communities of epiphytic plants (mainly mosses and lichens) and animals. Large branches are the home of myriad invertebrates, as well as birds and arboreal mammals. Branches in the upper third of the canopy are more numerous and regular in shape; they resemble those of younger trees.

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[7] The deep crowns of many old-growth Douglas-firs in old-growth forests of the Cascade Range have been the subject of considerable discussion among the authors. Douglas-fir crowns in many natural 75- to 150-year-old stands are quite short; live branch systems are confined to the upper one-third to one-fourth of the bole. It is hard to imagine how these trees could develop crowns similar to those of existing old-growth trees, even after several centuries. Epicormic branching is probably one factor. We also think that existing old growth originally developed in stands that were understocked; under such conditions, branch systems might persist much lower in the crown. A wide range in ages of dominant old-growth Douglas-firs in many stands does provide some evidence of low densities in original stands (Franklin and Waring 1980). If our inference about low tree densities being a factor in old-growth crown forms is correct, one implication would be that dominant Douglas-firs in many existing second-growth stands would not develop the "classical" old-growth form of crown. They might, however, develop the alternate form of crown often observed in the Coast Ranges and discussed later in this report.

Figure 13. Long-lived species in the other forest types can attain the sizes of old-growth Douglas-fir and fulfill comparable ecological roles: Old-growth Sitka spruce (A) in coastal forests attain diameters of 60 inches (150 cm) or more and have massive epiphyte-laden branch systems. Noble fir (B) attains the largest size of any subalpine species but lacks a deep crown and dense branch system. Old-growth western redcedar (C) and Port-Orford-cedar (D) can be large specimens functionally comparable to old-growth Douglas-fir in many respects.

Old-growth trees frequently have broken tops, in which case one or several lateral branches may have grown upward and assumed leadership. Lateral branches of these secondary tops resemble those in the upper portion of an intact top.

Most stands have occasional old trees with their crowns concentrated at the top of the trunk in a spherical rather than a cylindrical form. Such

rees often overtop the adjacent anopy. The crowns of these trees re dominated by much larger limbs han are found in cylindrical crowns. his spherical form of crown seems nore characteristic of old-growth tands in the Coast Ranges than of nose on the west side of the Casade Range and may reflect crowns eveloped in a denser stand (see ootnote 7).

ew old-growth Douglas-firs have ertical trunks. The lower trunk eans away from the hillside but beomes nearly vertical where it exends above the surrounding anopy. Trunks on level sites appear slope almost at random. Even a ight inclination of a trunk results an important differentiation of abitat on its two sides. The upper side gets almost all the moisture, both from direct precipitation and from stem flow and throughfall. Consequently, it is colonized by epiphytic plants (plants that grow on other plants) with relatively high moisture requirements, chiefly mosses. The lower side is a "desert" occupied by scattered colonies of lichens (Pike et al. 1975) that form a crust over the bark surface. The bark on the wet upper side is soft and easily eroded, sometimes appearing to be held in place by its mantle of mosses and lichens, whereas the bark on the lower side is hard and deeply furrowed, indicating that it remains in place for longer periods.

Old specimens of other tree species can play a role comparable to that of Douglas-fir to at least some degree, although none have been as thoroughly studied (fig. 13). Sitka spruce attains comparable sizes in coastal regions; irregular crown systems and heavy, epiphyte-laden branch systems are characteristic of older specimens. Noble fir and western white pine are subalpine species with some, but not all, of the distinctive characteristics of Douglas-fir, as is sugar pine in southwestern Oregon. The so-called cedars—western redcedar, Alaska-cedar, Port-Orford-cedar, and incense-cedar—are capable of attaining sizes and fulfilling roles comparable to Douglas-fir in their respective types. These species have the additional advantage of fostering improved soil conditions through their base-rich litter. The major climax species—western hemlock, Pacific silver fir, and grand fir—appear, on the other hand, to lack the ability to completely fulfill the ecological roles of these long-lived pioneers.

Table 9—Temperature regime in an old-growth Douglas-fir tree canopy as related to precipitation during the current and preceding day[1]

Precipitation, current and preceding day	Days		Maximum daily temperature		Daily temperature range	
	Sept. 1976 to Aug. 1977	Sept. 1977 to Aug. 1978	Mean	Standard error	Mean	Standard error
Millimeters	——Number——		——————— °Celsius ———————			
0	195	124	18.8	± 11.2	13.1	± 6.8
0.1- 10.0	91	111	11.7	± 7.8	7.8	± 4.8
10.1- 20.0	35	48	9.5	± 6.0	5.8	± 4.0
20.1- 30.0	18	34	8.8	± 4.8	5.3	± 3.3
30.1-100	26	48	7.5	± 3.7	4.0	± 1.9

[1] An increasingly wet canopy results in lower minimum temperatures and a smaller diurnal range in temperature.

What ecological roles does a live, old-growth tree fulfill? There are many, but the most important are related to: (1) provision of habitat for the distinctive epiphytic plant and animal communities found in an old-growth forest; (2) effects on carbon, nutrient, and water cycling, especially the N budget of the site; and (3) source material for the other key structural components—standing dead trees, logs on land, and logs in streams.

Habitat Function. Many of the distinctive compositional features of old-growth forests—plants and animals—are related to the tree canopies. Almost every surface of an old-growth Douglas-fir is occupied by epiphytic plants; more than 100 species of mosses and lichens function as these epiphytes. The dry weight of mosses and lichens on a single old-growth tree ranges from 33 to 66 pounds (15 to 30 kg) (Pike et al. 1977), of which less than half is mosses; this excludes the ubiquitous crust-forming lichens which cannot be separated for weighing. In forests below 3,500-foot (1 000-m) elevation, about half the total weight of epiphytes is usually due to a single leafy or "foliose" lichen, *Lobaria oregana*, which is an active N fixer. Although lichens are found over almost all surfaces, many species are restricted to particular habitats (see table 1 in Pike et al. (1975) for an excellent illustration of this point). *Lobaria oregana*, for example, occurs chiefly on the upper sides of branches and twigs. *Lepraria membranacea*, on the other hand, prefers the lower trunk and the underside of branches. Nearly all mosses occur on the bottom half of a tree.

Epiphytic communities remove soluble mineral nutrients from water flowing over them. They also trap dust and litter fragments, including needles. This accumulation, augmented by decomposition of the epiphytes themselves, is most evident on the upper sides of large branches where it results in the formation of perched "soils."

When moist, the old-growth forest canopy is an important climatic buffer, a fact that may explain some of the special compositional and functional features of the canopy. Air temperatures in the canopy of an old-growth Douglas-fir stand in the western Cascade Range of Oregon can range as high as 104 °F (40 °C) during the summer and as low as 14 °F (−10 °C) during dry periods in the winter. When the canopy is wet, however, temperatures range from 32 °F to 60 °F (0 °C to 15 °C) (table 9). As precipitation increases, daily maximum temperatures and the daily temperature range decrease. This buffering reflects the large water-holding capacity of the canopy—about 264,000 gallons per acre (3×10^6 liters/ha)—equivalent to 1¼ inches (3 cm) of precipitation.

This environmental regime is important to survival of *Lobaria oregana* and may be to other canopy inhabitants. *Lobaria*, the dominant epiphytic lichen in old-growth stands on the west slope of the Cascade Range, is metabolically active when wet and dormant when dry. One-half to 1 inch (1 to 2 cm) of rainfall will wet the canopy sufficiently to raise the water content of the *Lobaria* above 70 percent. Below this moisture level, the lichen ceases to

ix N and is presumably protected gainst temperature extremes by lormancy. A moistened thallus vould never be subjected to high emperatures because of the anopy's buffering (fig. 14). *Lobaria regana* appears to be limited to abitats where moist conditions are lways associated with cool emperatures, such as is charac-eristic of an old-growth canopy. Vhen *Lobaria* thalli are transplanted o stands of young growth or mixed onifer-hardwood, they deteriorate apidly, presumably because air emperatures exceed 60°F (15°C) nd thalli are hydrated. *Lobaria ore-ana* usually does not occur in oung Douglas-fir stands, possibly ecause their canopies hold insuffi-ient moisture for adequate thermal uffering. It may be abundant on in-ividual young trees in old-growth tands, however, where the urrounding mature trees provide an ppropriate microclimate.

he canopy of an old-growth ouglas-fir forest harbors large num-ers of invertebrates of many pecies. A single stand may have iore than 1,500 species. A minority f species spend their entire cycle the canopy: Araneida, Acarina, omoptera, Collembola, Neuroptera, hysanoptera, and Psocoptera. ther species of Lepidoptera, Hy-ienoptera, Diptera, and Coleoptera ccur as eggs, larvae, and pupae in ie canopy; but the adults can and o move out of the canopy. The ma-rity of species encountered in the anopy are adults that spend their nmature stages on the forest floor r in streams. In their canopy :udies, Drs. George Carroll (Univer-ty of Oregon) and William Denison)regon State University) discovered verwintering caddisfly adults in ouglas-fir canopies. Many adults of pecies of Mycetophilidae (fungus nats) trapped in the canopy occur s larvae in the abundant mush-oms on the forest floor.

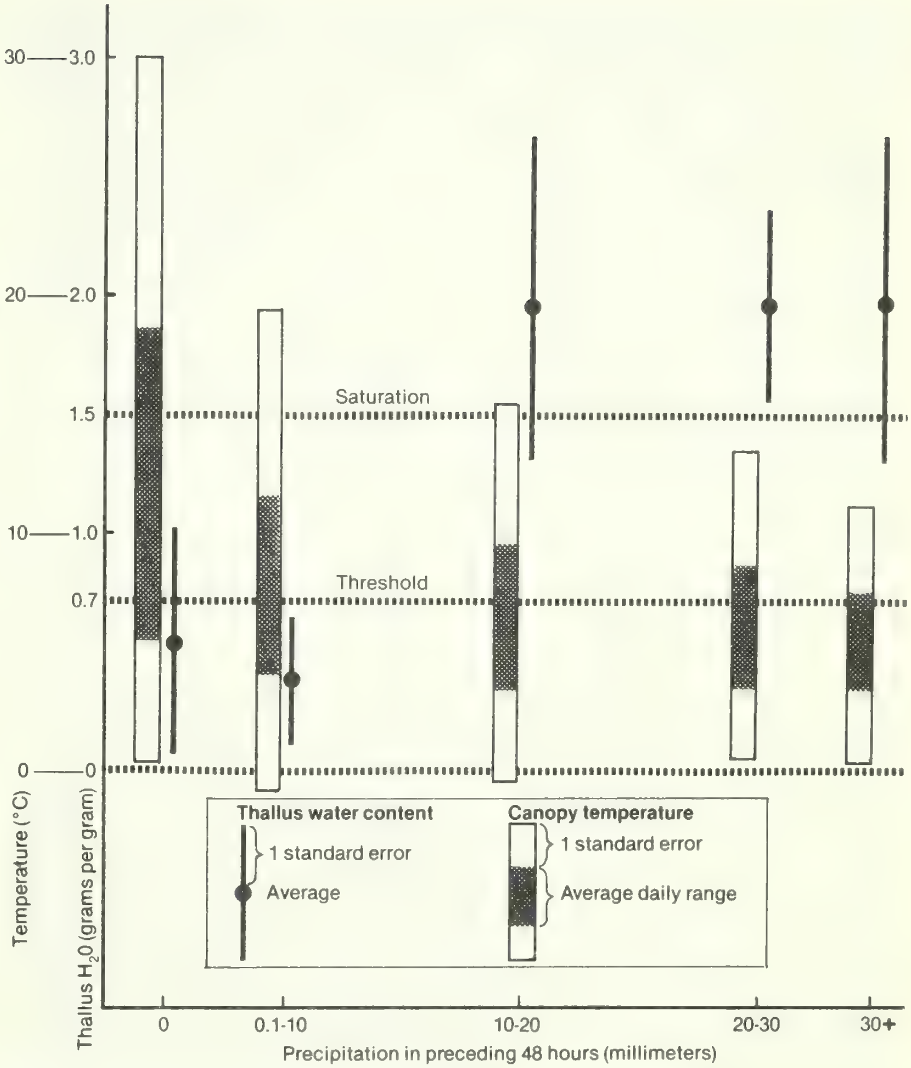

*Figure 14. Relationship between canopy temperature, lichen (*Lobaria oregana*) thallus water content, and precipitation in the preceding 48 hours. Several thresholds are indicated: 0°C which is the lower thermal limit for nitrogen fixation; 70-percent thallus water content which is the lower moisture limit for nitrogen fixation; and 16°C which is the upper thermal limit (tolerance) for a saturated* Lobaria *thallus.*

Although primary consumers (insects—such as sawflies, scales, or aphids—which feed on foliage or beetles which feed on wood) do occur in the canopy, they are not abundant. The most abundant arthropods are predaceous spiders, which belong to families such as Salticidae and Thomisidae. The large numbers of flies found in the canopy probably provide food for the spiders. Other arthropods feed on debris or on bacteria and fungi on surfaces of the canopy or are predators of other invertebrates. During one sampling period, invertebrates washed from foliage samples included:

Food source	*Invertebrates*
Needles	1 species of scale 1 species of mealy bug 1 species of Lepidoptera
Bacteria and fungi living on needles	6 species of mites 4 species of flies (as larvae) 5 species of Collembola
Other invertebrates	2 species of mites 2 species of spiders

The canopy of an old-growth forest provides several insect habitats, both vertically and horizontally. Some species are found in the upper canopy, others in the lower; some species occur on major limbs and others among twigs and foliage.

Several vertebrates depend heavily on the old-growth canopy as sites for nesting, feeding, and protection. Well-known examples are the northern spotted owl, northern flying squirrel, and red tree vole. The vole may live for many generations in the same tree. The role that the large branch systems and organic accumulations play in providing suitable habitat should not be overlooked.

Cycling Function. Old-growth trees are one of the primary sites for photosynthesis, or production of the food base, on which the rest of the system depends. In this sense, they are the same as younger trees, except that each tree represents a large accumulation of organic material and nutrients (a "sink" in the short run and a "storehouse" in the long run) as well as a large photosynthetic factory. A single old-growth tree can have over 60 million individual needles with a cumulative weight of 440 pounds (200 kg) and a surface area of 30,000 square feet (2 800 m^2) (Pike et al. 1977). Total leaf areas in old-growth stands are probably not much different from those in younger stands, but the leaves are concentrated on fewer individuals. Fluctuations in production and live biomass strongly reflect mortality of these large dominant trees, which are both factory and storehouse, and the rate at which other trees occupy the vacated space.

A distinctive and unusual functional role of an old-growth tree is its contribution to the nitrogen economy of low-elevation to midelevation sites. Lichens that inhabit the canopy fix significant amounts of N which ultimately become available to the whole forest through leaching, litterfall, and decomposition. Estimates of fixed N range from 2.5 to 4.5 pounds per acre (3 to 5 kg/ha) per year. Most of the fixation is accomplished by *Lobaria oregana*, although several other large foliose lichens, such as *L. pulmonaria*, *Pseudocyphellaria rainierensis*, and *Peltigera aphthosa*, are also azotodesmic[8] and, therefore, capable of fixing atmospheric N. *Lobaria oregana* accounts for half the total epiphytic biomass in the western Oregon Douglas-fir stands that have been studied. *Lobaria* and most N-fixing epiphytes are not common in young-growth stands, and this may be related to the microclimate of the old-growth forest canopy. Significant epiphytic inputs of N are, therefore, largely confined to old growth. Nitrogen-fixing bacteria on Douglas-fir foliage have not been found in the Pacific Northwest, even though they have been reported in Europe.

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[8] Azotodesmic lichens contain a blue-green alga, either as a primary plant symbiont or a secondary one, and therefore are capable of fixing N. Nonazotodesmic lichens contain a green alga as the sole algal symbiont and are not capable of fixing N.

Standing Dead Trees or Snags. In any old-growth stand there are substantial numbers of standing dead trees or snags (fig. 15). Indeed, snags were the first dead component of natural forests of which foresters were made aware—initially because of the fire and safety hazard they represent and, more recently, because of their value to wildlife (Bull and Meslow 1977, Bull 1978, Thomas et al. 1979a, Mannan et al. 1980). Some representative data for old-growth stands are provided in table 10. The only comprehensive study on dynamics of snags is by Cline et al. (1980), who studied 30 stands from 5 to 440 years old in the Coast and Cascade Ranges. Densities of snags decrease with stand age, but mean d.b.h. of snags increases from 5 to 29 inches (13 to 72 cm) between stand ages 35 and 200; larger snags survive longer. Cline et al. (1980) report mean densities of snags over 3.6-inch (9-cm) d.b.h. at 13.8 per acre (34.6/ha) and 7.3 per acre (18.3/ha) in stands 120 and 200 years old, respectively. These values, as well as a life table (model) estimate of 9.2 snags per acre (23/ha) for a 200-year-old stand, are substantially below the densities in table 10; all six of the old-growth stands of Cline et al. (1980) are located in the Coast Ranges.

A

B

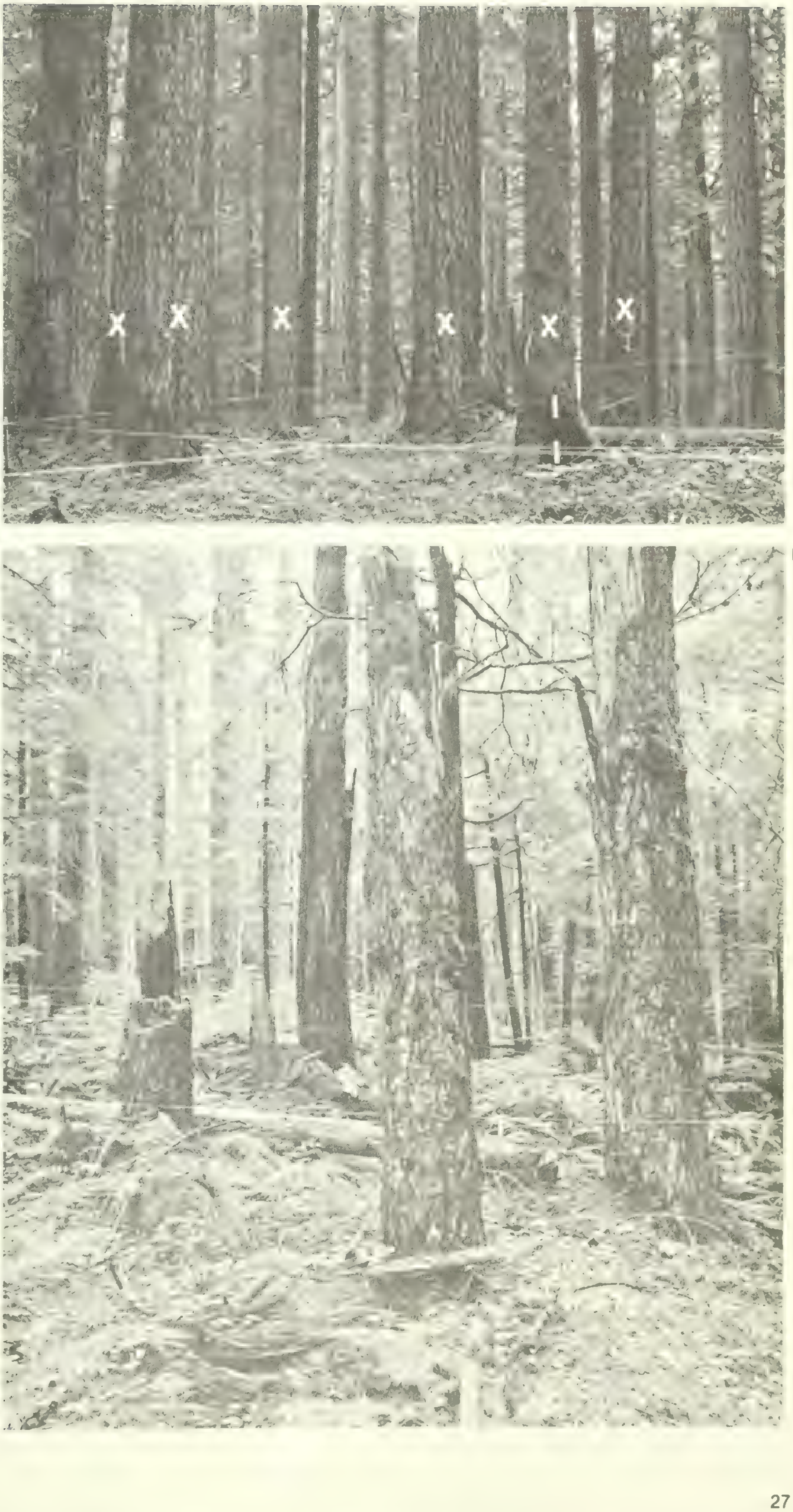


Figure 15. Large numbers of standing dead trees or snags are characteristic of old-growth forests. A. The volume and numbers of standing dead trees may not be apparent to the casual observer in this 250-year-old Douglas-fir stand in the Bagby Research Natural Area, Mount Hood National Forest; dead stems are marked with an X. B. Heavily decomposed snags in old-growth Douglas-fir–western hemlock stand.

Table 10—Numbers of standing dead trees >13 feet (>4 m) in height and mean d.b.h. in age sequence of old-growth Douglas-fir–western hemlock stands in the Cascade Range[1]

Forest age	Stands sampled	Height: 13-31 feet (4-9 m)	Height: 32-64 feet (10-19 m)	Height: >65 feet (>20 m)	Height: All	Mean d.b.h.
Years	Number	Number/acre (number/ha)				Inches (centimeters)
250	2	10 (26)	9 (22)	5 (12)	24 (60)	16 (42)
450	6	6 (16)	4 (10)	2 (6)	13 (32)	22 (57)
850 +	3	7 (17)	5 (12)	2 (4)	13 (33)	25 (64)

[1] Short snags or stubs (<13 ft or <4 m in height) average about 61 per acre (152/ha) in 7 old-growth stands ranging from 250 to 1,000 years old; there is no apparent trend in numbers with age of stand in this small sample.

The large standing dead stems in excess of 20-inch (50 cm) d.b.h. and 65-foot (20-m) height are most valuable to wildlife (Scott 1978). Mannan et al. (1980) found hole-nesting birds usually used snags over 24-inch (60-cm) d.b.h. and 50 feet (15 m) tall in western Oregon. Density and diversity of species of hole-nesting birds were significantly related to mean diameter of snags. Smaller snags apparently do not provide suitable habitat for some animal species, and some tree species are preferred by hole-nesters (McClelland et al. 1979). Under natural conditions, large snags are not strictly a unique attribute of old-growth stands. Young-growth forests developing after wildfires have large residual snags from the original stand for various lengths of time. Cline et al. (1980) found residual or remnant snags in young-growth forest up to the oldest (110-year) age class they studied. Our experience is that large Douglas-fir snags typically persist for 50 to 75 years before being reduced to stubs less than 35 feet (10 m) in height; snags of western redcedar may remain essentially whole and standing for 75 to 125 years.

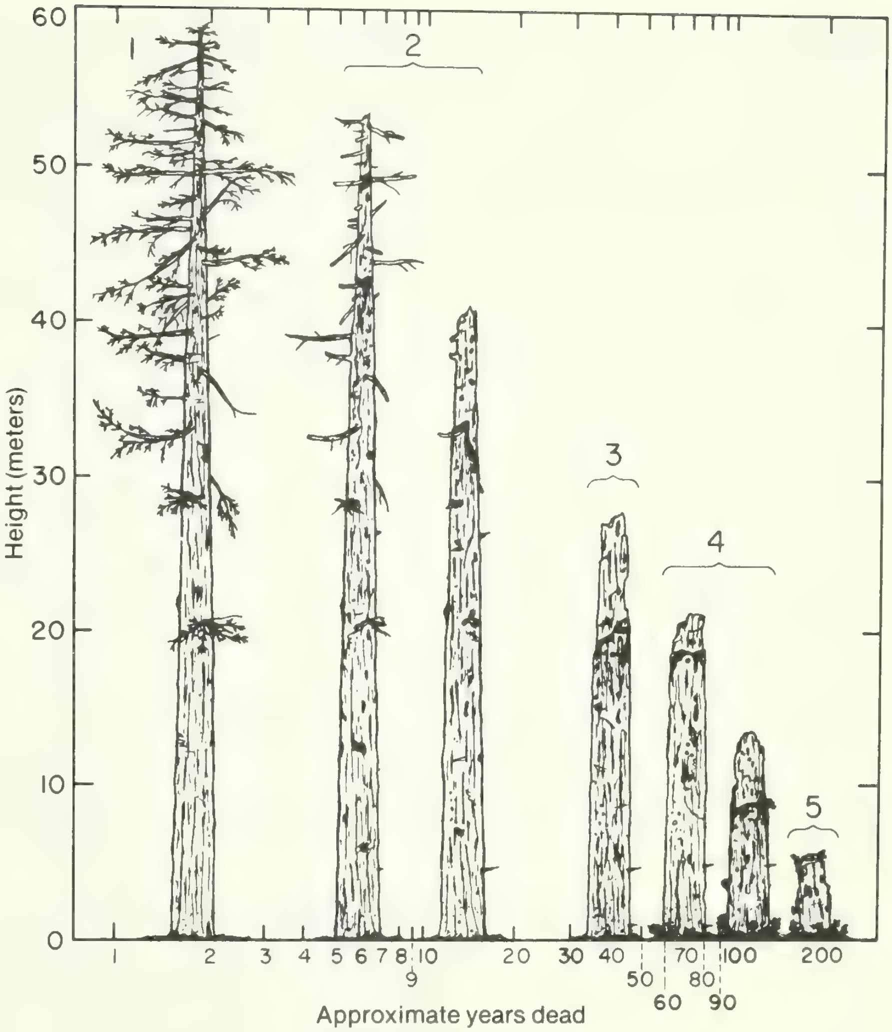
Large snags result from large trees; so they are a special product of old-growth forests. Managed young stands lack the residual snags of postwildfire stands unless snags are specifically planned. Natural stands appear to require about 150 years to develop snags 20 inches (50 cm) in diameter (Cline et al. 1980). Cline et al. (1980) suggest a life table approach for predicting densities and sizes of snags and recommend retention of large, defective trees for future snags in second-growth forests.

Various classifications, based on external features, have been developed for snags (Cline 1977, Cline et al. 1980, Thomas et al. 1979a); in general, these describe a time sequence in decomposition and disintegration of a dead tree (fig. 16). It is important to differentiate the stages of a snag since these are associated with changing values for wildlife. Both the path (stages) and the rate of disintegration of snags vary widely, however, depending on such factors as tree species, incidence and extent of decay at time of death, and environmental conditions. Douglas-fir snags typically disintegrate from the top down, losing the top and bark first. The trunk finally breaks off in large chunks, leaving a short snag or stub. Western redcedar and western white pine, on the other hand, often form bark-free, gray "buckskin" snags and remain essentially entire until they rot away at ground level and fall.

Habitat Function. A primary role of standing dead trees is the provision of habitat for wildlife. This has been discussed by Thomas et al. (1979a) for the Blue Mountains of Oregon and Washington. Snags in that area are the primary location for cavities that are used by 63 species of vertebrates—39 birds and 24 mammals. Uses include sites for nesting and overwintering, locations for courtship rituals, and food sources.

Thomas et al. (1979a) indicate a direct correlation between numbers of snags and related populations since suitable nesting sites are generally thought to limit populations; Mannan et al. (1980) confirm this for hole-nesting birds in western Oregon. The large, hard snags required by primary excavators, such as the pileated woodpecker (*Dryocopus pileatus*), are especially important. Such snags will be hard to perpetuate in managed stands because of smaller trees and programs for salvaging wood and reducing fire and safety hazards); yet such snags are also suited to other wildlife species and will produce soft snags through the process of deterioration. Snags representing a variety of decay classes are needed in a stand to meet the differing requirements of vertebrates since not all use the same material. One special attribute of old-growth and large (natural), second-growth stands is that they provide the necessary array of snags with varying levels of decay, whereas young stands on cutover areas do not.

Cycling Function. Most of the functional roles (in energy and nutrient cycling, including sites for microbial nitrogen fixation) of standing dead trees are the same as those of logs and will be considered in the discussion of logs.



Standing dead trees do not necessarily disintegrate at the same rate or in the same way as logs and cannot be considered simply as vertical, dead trees (or vice versa) in terms of decay rates and agents. An old-growth Douglas-fir that dies standing appears to deteriorate much more rapidly if it remains standing than a tree of comparable size that dies by windthrow. The activity of invertebrate and vertebrate animals, gravity, wind, and the effect of rapidly alternating environmental conditions may all be factors involved in the more rapid disintegration of snags. This difference in the rate and nature of decomposition is, perhaps, the primary functional contrast between down trees and snags.

Figure 16. Successional or decompositional evolution of a standing dead Douglas-fir tree (courtesy Steve Cline).

A

B

Figure 17. Large masses of logs can be a dominant feature of old-growth forests, as illustrated in these stands with near-maximal accumulations: A. Midelevation stand of old-growth Douglas-fir in the western Cascade Range of Oregon. B. Old-growth stand of noble fir near Mount St. Helens, Washington.

ɔgs on Land. Logs, also describa- e as down dead trees or coarse ɔody debris, are nearly as conspic- ıus as the large, live trees. Large asses of logs can be the dominant ature of old-growth forests (fig.), and, in numbers, volume, and ight of organic matter, they con- tute an important component. om 38 to 85 tons per acre (85 to 0 tonnes/ha) are typical values at have been reported. Down logs eraged 85 tons per acre over a -acre (10-ha) watershed covered th old-growth Douglas-fir–western mlock forest (Grier and Logan 77). Amounts within the watershed nged widely —the lightest weights tons/acre or 55 tonnes/ha) on a ridgetop and the heaviest (259 ns/acre or 581 tonnes/ha) on a ver slope, streamside area. sses by downslope transfer had curred on the ridgetop, and bstantial amounts of debris had cumulated on the lower slope. In 0-acre (4-ha) midelevation stand Douglas-fir, western hemlock, and e firs, there were 82 tons of bris per acre (182 tonnes/ha),[9] 55 rcent as recently fallen trees. gs occupied 29 percent of the est floor in this stand (fig. 18).

[9] acMillan, Paul C., Joseph E. Means, mit Cromack, Jr., and Glenn M. Hawk. ıglas-fir decomposition, biomass, and rient capital in the western Cascades, gon. 65 p. Unpublished manuscript on at Forestry Sciences Laboratory, Cor- lis, Oreg.

The average weight of down logs in seven old-growth stands, from 250 to over 900 years old, was 53 tons per acre (118 tonnes/ha);[10] the range was 38 to 70 tons per acre (85 to 156 tonnes/ha).[11] The largest accumulation of down wood recorded for a stand thus far is in the Carbon River Valley at Mount Rainier National Park; a hectare plot contains 188 tons per acre (418 tonnes/ha) of logs that covered 23 percent of the plot.

Logs are also major pools of important nutrients, such as N and phosphorus (P). In the old-growth watershed, the log component contained 192 pounds per acre (215 kg/ha) of N and 6.0 pounds per acre (6.7 kg/ha) of P (Grier and Logan 1977). In the midelevation stand, coarse woody debris contained 485 pounds per acre (544 kg/ha) of N (see footnote 9).

[10] Unpublished data on file at Forestry Sciences Laboratory, Corvallis, Oreg. Stands are at low to middle elevations in the northern Oregon and southern Washington Cascade Range (from H. J. Andrews Experimental Forest, Oregon, to Mount Rainier National Park, Washington).

[11] Weights of down logs and stand age are only loosely correlated. Natural young Douglas-fir stands (about 100 years old), surveyed at the same time as the old growth, had masses of logs as large as some found in old-growth stands—primarily material carried over from previous stands as snags and logs. Large volumes of coarse woody debris are apparently characteristic of our natural forest ecosystems, adding credence to the concept of coarse woody debris as a mechanism to provide continuity of habitat from one forest generation to another (Maser et al. 1979) and for conserving large masses of organic matter and nutrients in major disturbances. It also suggests that the long-term ecological effects of nearly complete removal of woody debris in cutover stands and the prevention of new accumulations in intensively managed stands should be carefully examined.

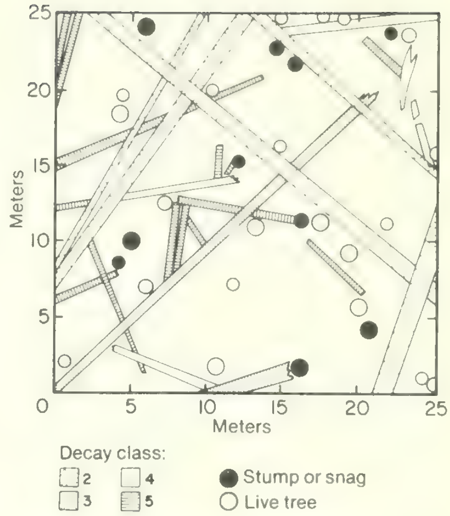


Figure 18. Down logs in midelevation stand of old growth in the H. J. Andrews Experimental Forest. Logs occupied 29 percent of the forest floor in this stand.

Table 11—A 5-class scheme for rating decomposition of Douglas-fir logs[1]

Characteristic	Decay class 1	2	3	4	5
Bark	intact	mostly intact	partially intact to sloughing	absent	absent
Twigs, 1.2-inch (3-cm)	present	absent	absent	absent	absent
Large branches	present	present	present	present	absent
Exposed wood texture	intact	intact to partly soft	large, hard pieces	small, soft, blocky pieces	soft and powdery (when dry)
Portion of log on ground	support points	support points and slightly sagging	log is sagging	all	all
Exposed wood color	original	original	original to red-brown	light brown to reddish	red-brown to dark brown
Epiphytes	none	none	conifer seedlings (≤3 years old)	moss and hem-lock seedlings	moss and hem-lock seedlings
Log shape	round	round	round	round	oval
Invading roots	none	none	confier seedlings	in sapwood only	in sapwood and heartwood
Characteristics not used that also apply:					
Fungal fruiting bodies	none	*Cyathus, Tremella, Mycena, Collybia, Polyporus, Fomitopsis, Pseudohydnum*	*Polyporus, Polyporellus, Pseudohydnum, Fomitopsis*	*Cortinarius, Mycena, Marasmius*	*Cortinarius, Collybia, Cantharellus*
Mycorrhizae	none	none	none	in sapwood	in sapwood and heartwood

[1] Adapted from Fogel et al. (1972).

N and is presumably protected ainst temperature extremes by rmancy. A moistened thallus ould never be subjected to high mperatures because of the nopy's buffering (fig. 14). *Lobaria egana* appears to be limited to bitats where moist conditions are ways associated with cool mperatures, such as is charac- istic of an old-growth canopy. hen *Lobaria* thalli are transplanted stands of young growth or mixed nifer-hardwood, they deteriorate pidly, presumably because air mperatures exceed 60°F (15°C) d thalli are hydrated. *Lobaria ore- na* usually does not occur in ung Douglas-fir stands, possibly cause their canopies hold insuffi- ent moisture for adequate thermal ffering. It may be abundant on in- vidual young trees in old-growth ands, however, where the rrounding mature trees provide an propriate microclimate.

e canopy of an old-growth uglas-fir forest harbors large num- rs of invertebrates of many ecies. A single stand may have re than 1,500 species. A minority species spend their entire cycle the canopy: Araneida, Acarina, moptera, Collembola, Neuroptera, ysanoptera, and Psocoptera. her species of Lepidoptera, Hy- noptera, Diptera, and Coleoptera cur as eggs, larvae, and pupae in canopy; but the adults can and move out of the canopy. The ma- ity of species encountered in the nopy are adults that spend their mature stages on the forest floor in streams. In their canopy idies, Drs. George Carroll (Univer- y of Oregon) and William Denison egon State University) discovered erwintering caddisfly adults in uglas-fir canopies. Many adults of ecies of Mycetophilidae (fungus ats) trapped in the canopy occur larvae in the abundant mush- oms on the forest floor.

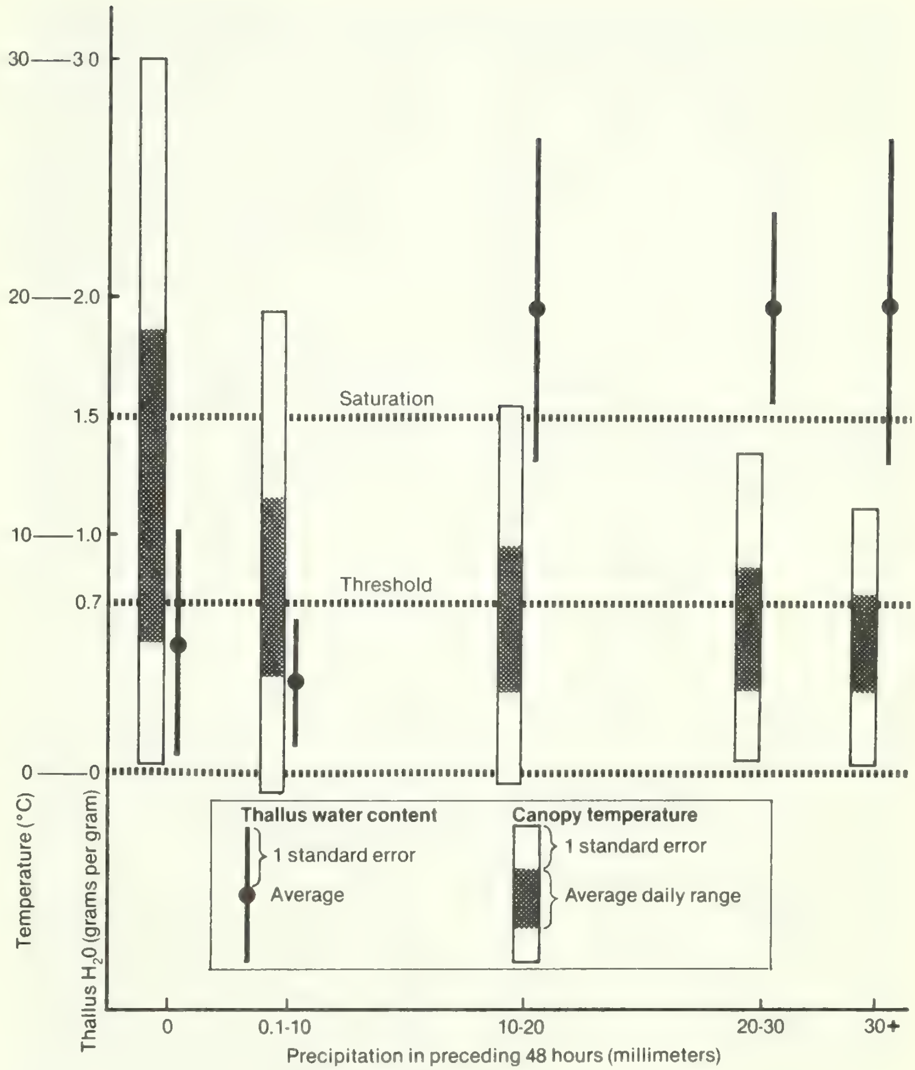


*Figure 14. Relationship between canopy temperature, lichen (*Lobaria oregana*) thallus water content, and precipitation in the preceding 48 hours. Several thresholds are indicated: 0°C which is the lower thermal limit for nitrogen fixation; 70-percent thallus water content which is the lower moisture limit for nitrogen fixation; and 16°C which is the upper thermal limit (tolerance) for a saturated* Lobaria *thallus.*

Although primary consumers (insects—such as sawflies, scales, or aphids—which feed on foliage or beetles which feed on wood) do occur in the canopy, they are not abundant. The most abundant arthropods are predaceous spiders, which belong to families such as Salticidae and Thomisidae. The large numbers of flies found in the canopy probably provide food for the spiders. Other arthropods feed on debris or on bacteria and fungi on surfaces of the canopy or are predators of other invertebrates. During one sampling period, invertebrates washed from foliage samples included:

Food source	*Invertebrates*
Needles	1 species of scale 1 species of mealy bug 1 species of Lepidoptera
Bacteria and fungi living on needles	6 species of mites 4 species of flies (as larvae) 5 species of Collembola
Other invertebrates	2 species of mites 2 species of spiders

The canopy of an old-growth forest provides several insect habitats, both vertically and horizontally. Some species are found in the upper canopy, others in the lower; some species occur on major limbs and others among twigs and foliage.

Several vertebrates depend heavily on the old-growth canopy as sites for nesting, feeding, and protection. Well-known examples are the northern spotted owl, northern flying squirrel, and red tree vole. The vole may live for many generations in the same tree. The role that the large branch systems and organic accumulations play in providing suitable habitat should not be overlooked.

Cycling Function. Old-growth trees are one of the primary sites for photosynthesis, or production of the food base, on which the rest of the system depends. In this sense, they are the same as younger trees, except that each tree represents a large accumulation of organic material and nutrients (a "sink" in the short run and a "storehouse" in the long run) as well as a large photosynthetic factory. A single old-growth tree can have over 60 million individual needles with a cumulative weight of 440 pounds (200 kg) and a surface area of 30,000 square feet (2 800 m^2) (Pike et al. 1977). Total leaf areas in old-growth stands are probably not much different from those in younger stands, but the leaves are concentrated on fewer individuals. Fluctuations in production and live biomass strongly reflect mortality of these large dominant trees, which are both factory and storehouse, and the rate at which other trees occupy the vacated space.

A distinctive and unusual functional role of an old-growth tree is its contribution to the nitrogen economy of low-elevation to midelevation sites. Lichens that inhabit the canopy fix significant amounts of N which ultimately become available to the whole forest through leaching, litter fall, and decomposition. Estimates of fixed N range from 2.5 to 4.5 pounds per acre (3 to 5 kg/ha) per year. Most of the fixation is accomplished by *Lobaria oregana*, although several other large foliose lichens, such as *L. pulmonaria*, *Pseudocyphellaria rainierensis*, and *Peltigera aphthosa*, are also azotodesmic[8] and, therefore, capable of fixing atmospheric N. *Lobaria oregana* accounts for half the total epiphytic biomass in the western Oregon Douglas-fir stands that have been studied. *Lobaria* and most N-fixing epiphytes are not common in young-growth stands, and this may be related to the microclimate of the old-growth forest canopy. Significant inputs of N are, therefore, largely confined to old growth. Nitrogen-fixing bacteria on Douglas-fir foliage have not been found in the Pacific Northwest, even though they have been reported in Europe.

[8] Azotodesmic lichens contain a blue-green alga, either as a primary plant symbiont or a secondary one, and therefore are capable of fixing N. Nonazotodesmic lichens contain a green alga as the sole algal symbiont and are not capable of fixing N.

tanding Dead Trees or Snags. In ny old-growth stand there are substantial numbers of standing dead ees or snags (fig. 15). Indeed, nags were the first dead component of natural forests of which presters were made aware—initially ecause of the fire and safety azard they represent and, more cently, because of their value to ildlife (Bull and Meslow 1977, Bull 978, Thomas et al. 1979a, Mannan al. 1980). Some representative ata for old-growth stands are proded in table 10. The only comprehensive study on dynamics of snags by Cline et al. (1980), who studied) stands from 5 to 440 years old in e Coast and Cascade Ranges. ensities of snags decrease with and age, but mean d.b.h. of snags creases from 5 to 29 inches (13 to cm) between stand ages 35 and 00; larger snags survive longer. ine et al. (1980) report mean densies of snags over 3.6-inch (9-cm) b.h. at 13.8 per acre (34.6/ha) and 3 per acre (18.3/ha) in stands 120 d 200 years old, respectively. ese values, as well as a life table odel) estimate of 9.2 snags per re (23/ha) for a 200-year-old stand, e substantially below the densities table 10; all six of the old-growth ands of Cline et al. (1980) are cated in the Coast Ranges.


A


B

gure 15. Large numbers of standing ad trees or snags are characteristic of d-growth forests. A. The volume and mbers of standing dead trees may not apparent to the casual observer in 's 250-year-old Douglas-fir stand in the gby Research Natural Area, Mount od National Forest; dead stems are rked with an X. B. Heavily decomsed snags in old-growth Douglas--western hemlock stand.

Table 10—Numbers of standing dead trees >13 feet (>4 m) in height and mean d.b.h. in age sequence of old-growth Douglas-fir-western hemlock stands in the Cascade Range[1]

Forest age	Stands sampled	Height: 13-31 feet (4-9 m)	32-64 feet (10-19 m)	>65 feet (>20 m)	All	Mean d.b.h.
Years	Number	Number/acre (number/ha)				Inches (centimeters)
250	2	10 (26)	9 (22)	5 (12)	24 (60)	16 (42)
450	6	6 (16)	4 (10)	2 (6)	13 (32)	22 (57)
850 +	3	7 (17)	5 (12)	2 (4)	13 (33)	25 (64)

[1] Short snags or stubs (<13 ft or <4 m in height) average about 61 per acre (152/ha) in 7 old-growth stands ranging from 250 to 1,000 years old; there is no apparent trend in numbers with age of stand in this small sample.

The large standing dead stems in excess of 20-inch (50 cm) d.b.h. and 65-foot (20-m) height are most valuable to wildlife (Scott 1978). Mannan et al. (1980) found hole-nesting birds usually used snags over 24-inch (60-cm) d.b.h. and 50 feet (15 m) tall in western Oregon. Density and diversity of species of hole-nesting birds were significantly related to mean diameter of snags. Smaller snags apparently do not provide suitable habitat for some animal species, and some tree species are preferred by hole-nesters (McClelland et al. 1979). Under natural conditions, large snags are not strictly a unique attribute of old-growth stands. Young-growth forests developing after wildfires have large residual snags from the original stand for various lengths of time. Cline et al. (1980) found residual or remnant snags in young-growth forest up to the oldest (110-year) age class they studied. Our experience is that large Douglas-fir snags typically persist for 50 to 75 years before being reduced to stubs less than 35 feet (10 m) in height; snags of western redcedar may remain essentially whole and standing for 75 to 125 years.

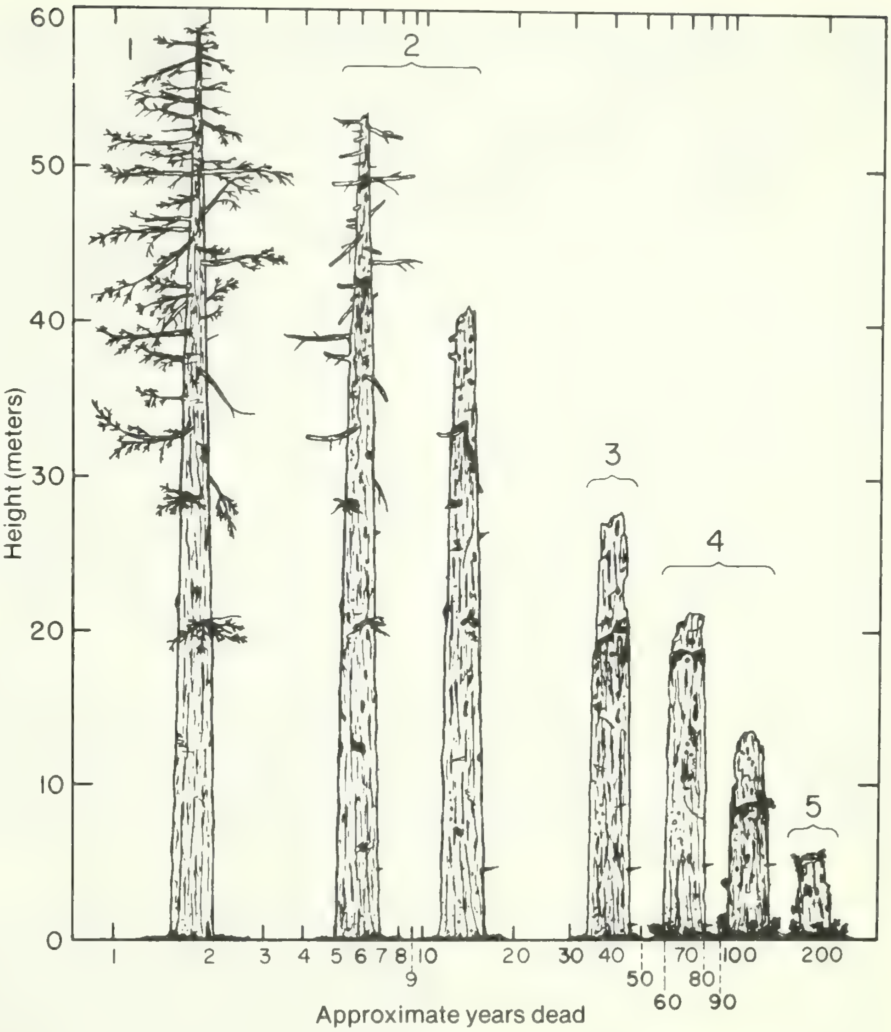
Large snags result from large trees; so they are a special product of old-growth forests. Managed young stands lack the residual snags of postwildfire stands unless snags are specifically planned. Natural stands appear to require about 150 years to develop snags 20 inches (50 cm) in diameter (Cline et al. 1980). Cline et al. (1980) suggest a life table approach for predicting densities and sizes of snags and recommend retention of large, defective trees for future snags in second-growth forests.

Various classifications, based on external features, have been developed for snags (Cline 1977, Cline et al. 1980, Thomas et al. 1979a); in general, these describe a time sequence in decomposition and disintegration of a dead tree (fig. 16). It is important to differentiate the stages of a snag since these are associated with changing values for wildlife. Both the path (stages) and the rate of disintegration of snags vary widely, however, depending on such factors as tree species, incidence and extent of decay at time of death, and environmental conditions. Douglas-fir snags typically disintegrate from the top down, losing the top and bark first. The trunk finally breaks off in large chunks, leaving a short snag or stub. Western redcedar and western white pine, on the other hand, often form bark-free, gray "buckskin" snags and remain essentially entire until they rot away at ground level and fall.

abitat Function. A primary role of anding dead trees is the provision habitat for wildlife. This has been scussed by Thomas et al. (1979a) r the Blue Mountains of Oregon nd Washington. Snags in that area e the primary location for cavities at are used by 63 species of verte- ates—39 birds and 24 mammals. ses include sites for nesting and rerwintering, locations for court- iip rituals, and food sources.

iomas et al. (1979a) indicate a rect correlation between numbers snags and related populations nce suitable nesting sites are nerally thought to limit popula- ons; Mannan et al. (1980) confirm is for hole-nesting birds in west- n Oregon. The large, hard snags quired by primary excavators, such the pileated woodpecker (*Dryo- pus pileatus*), are especially im- rtant. Such snags will be hard to rpetuate in managed stands ecause of smaller trees and pro- ams for salvaging wood and re- cing fire and safety hazards); yet ch snags are also suited to other ldlife species and will produce ft snags through the process of terioration. Snags representing a riety of decay classes are needed a stand to meet the differing re- irements of vertebrates since not use the same material. One spe- al attribute of old-growth and large atural), second-growth stands is at they provide the necessary ar- of snags with varying levels of cay, whereas young stands on tover areas do not.

cling Function. Most of the func- nal roles (in energy and nutrient cling, including sites for microbial rogen fixation) of standing dead ees are the same as those of logs d will be considered in the dis- ssion of logs.



Standing dead trees do not neces- sarily disintegrate at the same rate or in the same way as logs and can- not be considered simply as vertical, dead trees (or vice versa) in terms of decay rates and agents. An old- growth Douglas-fir that dies stand- ing appears to deteriorate much more rapidly if it remains standing than a tree of comparable size that dies by windthrow. The activity of in- vertebrate and vertebrate animals, gravity, wind, and the effect of rapidly alternating environmental conditions may all be factors in- volved in the more rapid disintegra- tion of snags. This difference in the rate and nature of decomposition is, perhaps, the primary functional con- trast between down trees and snags.

Figure 16. Successional or decomposi- tional evolution of a standing dead Douglas-fir tree (courtesy Steve Cline).

A

B

Figure 17. Large masses of logs can be a dominant feature of old-growth forests, as illustrated in these stands with near-maximal accumulations: A. Midelevation stand of old-growth Douglas-fir in the western Cascade Range of Oregon. B. Old-growth stand of noble fir near Mount St. Helens, Washington.

s on Land. Logs, also describa-
as down dead trees or coarse
dy debris, are nearly as conspic-
s as the large, live trees. Large
ses of logs can be the dominant
ure of old-growth forests (fig.
and, in numbers, volume, and
ght of organic matter, they con-
ite an important component.
n 38 to 85 tons per acre (85 to
tonnes/ha) are typical values
have been reported. Down logs
aged 85 tons per acre over a
cre (10-ha) watershed covered
old-growth Douglas-fir–western
lock forest (Grier and Logan
). Amounts within the watershed
ed widely —the lightest weights
ons/acre or 55 tonnes/ha) on a
idgetop and the heaviest (259
/acre or 581 tonnes/ha) on a
r slope, streamside area.
es by downslope transfer had
irred on the ridgetop, and
tantial amounts of debris had
mulated on the lower slope. In
-acre (4-ha) midelevation stand
ouglas-fir, western hemlock, and
firs, there were 82 tons of
is per acre (182 tonnes/ha),[9] 55
ent as recently fallen trees.
occupied 29 percent of the
t floor in this stand (fig. 18).

Millan, Paul C., Joseph E. Means,
it Cromack, Jr., and Glenn M. Hawk.
las-fir decomposition, biomass, and
ent capital in the western Cascades,
on. 65 p. Unpublished manuscript on
Forestry Sciences Laboratory, Cor-
, Oreg.

The average weight of down logs in seven old-growth stands, from 250 to over 900 years old, was 53 tons per acre (118 tonnes/ha);[10] the range was 38 to 70 tons per acre (85 to 156 tonnes/ha).[11] The largest accumulation of down wood recorded for a stand thus far is in the Carbon River Valley at Mount Rainier National Park; a hectare plot contains 188 tons per acre (418 tonnes/ha) of logs that covered 23 percent of the plot.

Logs are also major pools of important nutrients, such as N and phosphorus (P). In the old-growth watershed, the log component contained 192 pounds per acre (215 kg/ha) of N and 6.0 pounds per acre (6.7 kg/ha) of P (Grier and Logan 1977). In the midelevation stand, coarse woody debris contained 485 pounds per acre (544 kg/ha) of N (see footnote 9).

[10] Unpublished data on file at Forestry Sciences Laboratory, Corvallis, Oreg. Stands are at low to middle elevations in the northern Oregon and southern Washington Cascade Range (from H. J. Andrews Experimental Forest, Oregon, to Mount Rainier National Park, Washington).

[11] Weights of down logs and stand age are only loosely correlated. Natural young Douglas-fir stands (about 100 years old), surveyed at the same time as the old growth, had masses of logs as large as some found in old-growth stands—primarily material carried over from previous stands as snags and logs. Large volumes of coarse woody debris are apparently characteristic of our natural forest ecosystems, adding credence to the concept of coarse woody debris as a mechanism to provide continuity of habitat from one forest generation to another (Maser et al. 1979) and for conserving large masses of organic matter and nutrients in major disturbances. It also suggests that the long-term ecological effects of nearly complete removal of woody debris in cutover stands and the prevention of new accumulations in intensively managed stands should be carefully examined.

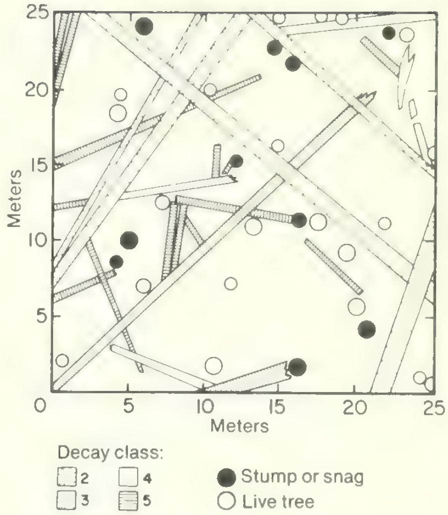


Figure 18. Down logs in midelevation stand of old growth in the H. J. Andrews Experimental Forest. Logs occupied 29 percent of the forest floor in this stand.

Table 11—A 5-class scheme for rating decomposition of Douglas-fir logs[1]

Characteristic	Decay class 1	2	3	4	5
Bark	intact	mostly intact	partially intact to sloughing	absent	absent
Twigs, 1.2-inch (3-cm)	present	absent	absent	absent	absent
Large branches	present	present	present	present	absent
Exposed wood texture	intact	intact to partly soft	large, hard pieces	small, soft, blocky pieces	soft and powdery (when dry)
Portion of log on ground	support points	support points and slightly sagging	log is sagging	all	all
Exposed wood color	original	original	original to red-brown	light brown to reddish	red-brown to dark brown
Epiphytes	none	none	conifer seedlings (≤3 years old)	moss and hemlock seedlings	moss and hemlock seedlings
Log shape	round	round	round	round	oval
Invading roots	none	none	confier seedlings	in sapwood only	in sapwood and heartwood
Characteristics not used that also apply:					
Fungal fruiting bodies	none	*Cyathus*, *Tremella*, *Mycena*, *Collybia*, *Polyporus*, *Fomitopsis*, *Pseudohydnum*	*Polyporus*, *Polyporellus*, *Pseudohydnum*, *Fomitopsis*	*Cortinarius*, *Mycena*, *Marasmius*	*Cortinarius*, *Collybia*, *Cantharellus*
Mycorrhizae	none	none	none	in sapwood	in sapwood and heartwood

[1] Adapted from Fogel et al. (1972).

ggest 50 to 100 acres (20 to 40 ha) r the nesting and feeding areas of vity-dwelling birds. Generally, 500 1,000 acres (200 to 400 ha) are eded for a third-order stream ainage. Areas much smaller than 0 acres (200 ha) can, on the other nd, preserve many attributes of d-growth forests, particularly if the undaries chosen for the area pre- nt rapid deterioration of the stand.

tire drainage basins, even for nall first- or second-order streams, e ecologically the most desirable its for old-growth forest manage- ent. Such drainages have natural pographic boundaries that often ovide superior protection from ndthrow and other external influ- ces for the reserved stand. A vari- y of ecological conditions are esent, along with a stream system which natural land-water inter- tions (for example, woody debris outs to the stream) can continue. ant and animal diversity will also higher in a drainage basin than an isolated upland forest stand of e same size.

other useful location for old- owth management areas is along eams. Streamside strips (buffer nes) were originally conceived for ading streams and minimizing in- eases in water temperatures; a ore valuable function in streams through at least third order is in oviding essential energy, struc- al inputs (for debris dams), and bility of banks. Debris dams must continually created to replace oken dams; this is particularly im- rtant after infrequent debris tor- ts that remove all, or most, ces of large debris. Streamside ips of old-growth forest will pro- ie for continued physical and bio- ical stability of the aquatic osystem.

Streamside and roadside strips of old growth have the additional advantage of providing migration routes for organisms dependent on mature forests. The strips skirt managed stands and provide continuity between otherwise isolated pockets of natural and old-growth forest. Such migration routes may be important for avoiding loss of species as "islands" of habitat suited to a species become more limited and isolated (MacClintock et al. 1977). The protected travel routes provided by these strips allow organisms to migrate in response to shifts in location of suitable habitat.

Reserve strips must be in appropriate locations and of sufficient size to survive normal windstorms. Streamside strips have often been narrow (since shading the stream was the primary objective) and sharp edged; consequently, they are extremely susceptible to blowdown. The wetter soils on lower slopes and streamsides do not make retention of strips any easier, and upslope harvesting often intensifies this problem. Regular programs to salvage logs on roadside or streamside strips are inappropriate because they accelerate deterioration of the stand and remove the essential structural components. Retention of dead wood is especially important for streams where it is the source of stabilizing debris dams. Salvage logging may be appropriate if losses from catastrophic windthrow or other causes occur. Even then, the salvage should not be complete; some down material should be selected and left on the land and in the stream. A 200-foot-wide (60-m) streamside or roadside strip is not a viable unit in most cases; considerable ingenuity and effort will be necessary to identify and lay out viable reserve strips.

Areas with problems that limit potential for management may also be appropriate sites for perpetuating old-growth ecosystems and organisms. An example could be steep landslide-prone headwall areas that depend on a strong and continuing root mantle for stability.

Structural Attributes in Perpetuating or Re-creating Old Growth. The distinctive structural features—the large, old-growth trees, snags, and logs on land and in streams—provide the major key to management strategies. The unique, important compositional and functional features of an old-growth forest usually accompany these structural elements.

An old-growth forest is much more than simply a collection of large trees. The dead, organic component is as important as the highly individualistic, large trees. Decaying snags and logs, particularly in streams, are beneficial and must be provided for in management schemes; they should not be viewed solely as waste, fire hazards, or impediments to management. Snags and logs play important roles as habitat for various organisms and in conserving and cycling nutrients and energy. To a large degree, success in managing forests for old-growth attributes will depend on learning to manage the dead, organic material as cleverly as the live trees.

There are implications here for management of old-growth stands selected for perpetuation. Salvage logging is inappropriate since it removes at least two of the major structural components—dead and down—that are key elements of the system. In all likelihood, some of the more decadent, live trees would also be removed. Salvage logging is also inappropriate because of the damage inevitably done to root systems and trunks of the residual stand which results in accelerated mortality of trees and overall deterioration of the stand.[17]

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[17] When stands are selected for preservation (for example, as roadside or streamside strips), the first (and frequently repeated) management activity is often a salvage program. If a manager wants to retain an old-growth ecosystem or a mature forest stand, entries should be avoided or at least minimized. Trees viewed as safety or fire hazards may better be felled and left in place than removed.

There are also implications if the manager wishes to create an old-growth environment (after a stand is cut) by using a long rotation. Initially, foresters may retain larger amounts of woody residues, especially down logs, from the previous stand. Retention of scattered individual, old-growth trees may be useful as sources of epiphytic flora and eventually of large, dead standing trees and down logs.

Rapid development of large, long-crowned trees as early as possible is a key objective of management that can be aided several ways. Selection of understocked stands of reproduction as sites for creating old-growth stands is one approach since individuals will grow faster and lose lower branches more slowly under open-grown conditions. Many existing old-growth stands may have regenerated slowly (Franklin and Waring 1980); growth patterns of individual trees suggest growing conditions essentially free from competition for a century or more. If initial densities of stands are moderate—at current recommended levels for managed stands—precommercial and commercial thinnings will be necessary during the first 100 years of a long-rotation forest management cycle. Growth rates of individual trees will be too low at high densities, or at moderate densities on less productive sites, to produce desired sizes of stems even after 200 years; thinnings and partial cuttings are essential under those conditions. Great care must be taken, however, to minimize damage to residual trees.

Creation of appropriate types and amounts of standing dead and down trees is a specific management objective. Snags and logs from the original stand should be avoided during intermediate cuttings. Up to about 100 years, the size of snags and logs produced by the young stand is probably not of particular ecological importance. Some of this material could be removed along with excess live trees—those that will die before reaching significant diameter (50 cm or 20 inches). Openings for development of shade-tolerant species can also be created this way; if these species do not come in naturally, they could be artificially introduced, possibly by underplanting. The large snags, logs, and any live old growth left from the original stand should not be removed during salvage operations.

After about 100 years, partial cutting of any type becomes increasingly inappropriate. There are fewer live dominants, and their loss, either directly by cutting or gradually through damage to roots and trunks, is undesirable. Standing dead trees and logs now being recruited from the live stands are of sufficient size to fully perform desired habitat and cycling functions.

To summarize, if the objective is perpetuation of an old-growth forest ecosystem, a minimum amount of disturbance should be allowed. Snags and logs perform important functions and are essential structures. When the objective is to create an old-growth forest from scratch, large individual trees with large crowns should be grown as quickly as possible. Scattered old-growth trees and rotten logs from the original stand should be retained and reproduction of western hemlock, western redcedar, and other shade-tolerant associates under the Douglas-fir canopies encouraged. Partial cuttings may be useful and will be necessary in moderate to heavily stocked stands of reproduction if large trees are to be attained as quickly as possible. After trees are about 100 years old, such cuttings are increasingly inappropriate, however.

For multiple-use objectives, an increased awareness of the nature and nontimber value of individual trees is important; for example, potential or current value as habitat for epiphytic communities and wildlife. Knowledge of the ecological roles of standing, dead trees and logs beyond their value as wildlife habitat is also desirable.

naging for Individual Old-Growth ributes

ere is considerable logic in man- ing entire stands or small drain- es for old-growth attributes. The d-growth ecosystem is a system of ny interlinked components, in- uding organisms. The serial rela- nship of the key structural com- nents has been discussed—from arge, old-growth tree to a nearly composed, rotten log (fig. 10). Fur- er, some organisms or functions y depend on an intact old-growth est for their perpetuation.

vertheless, a forester may wish to nage for some individual old- owth attributes. This is, in fact, w the forester can put some of e information on old growth to rk to increase ecological benefits m intensively managed timber- nds. The structural components ain provide the key. Perhaps most vious is providing for large snags d logs. This can be done in the st-generation managed forest by aining some of this material from e virgin stand. The tendency has en to remove all such materials a safety measure and to reduce gging residues, which are viewed fire hazards and impediments in generation and other silvicultural tivities. In second- and third- neration stands, a forester will ve to create appropriate materials ce neither large snags nor logs l usually be present.

The need for snags was recognized first by wildlife managers, and they have more recently recognized the value of logs (Maser et al. 1979, Thomas et al. 1979a). Thomas et al. (1979a) led in developing guidelines on sizes and numbers of such material needed to provide for vertebrates; although their research was conducted in the Blue Mountains of eastern Oregon and Washington, the same principles apply on the west side of the Cascade Range, as shown by Mannan et al. (1980) and Cline et al. (1980). These authors suggest that snags be created from defective, living trees and urge maintenance of large snags covering the spectrum of decomposition. Densities of snags in natural, old-growth stands are proposed as an interim management guide until more data are developed. Cline et al. (1980) also suggest leaving snags in groups to reduce problems of safety and fire control. It is important to remember that much more than habitat for vertebrate animals is involved in preserving snags; standing dead trees and logs serve other functions as well.[18]

There are currently no good guides to the number and sizes of logs that should be left on cutover areas. Removal of all coarse woody debris is not the best ecological practice. Costs and benefits of some practices (such as yarding unmerchantable material) are not known; negative impacts on long-term site productivity, wildlife, and erosion may offset the benefits to fire protection and ground accessibility. It does appear that at least several larger logs per acre are needed for wildlife, especially small mammals. Defining the types and sizes of logs and other woody debris desired in managed stands is a major problem for research.

Retention of small groups of old-growth trees, or scattered individual trees, may be a useful practice. This was conceived as a technique for providing a source of epiphytic "inoculum" for adjacent young trees. Lack of such a source may be a factor in the absence of the N-fixing epiphytes on trees less than 150 years old. Leaving occasional old-growth trees has another advantage —it will, in the long run, provide a source of large snags and logs. This may be the easiest strategy for perpetuating these structural components into second- and even third-generation managed stands.

[18] The role of dead wood in cycling and conserving nutrients, especially N, is an outstanding example. Ten years ago nothing was known about sources of N in old-growth stands, other than the atmospheric input. In the interim, epiphytic lichens and wood-dwelling bacteria have been identified as significant sites for fixation. There are several important sources for additions of N in both the early stages of forest succession—nonleguminous N fixers, such as alder (*Alnus* spp.) and ceanothus (*Ceanothus* spp.)—and in old-growth forests. Existing management strategies call for quick establishment of conifer canopies and short rotations—which effectively eliminate these additions of N to intensively managed sites.

Trees Mentioned in This Report

Common name	Scientific name
Alaska-cedar	*Chamaecyparis nootkatensis* (D. Don) Spach
Coast redwood	*Sequoia sempervirens* (D. Don) Endl.
Douglas-fir	*Pseudotsuga menziesii* (Mirb.) Franco
Grand fir	*Abies grandis* (Dougl. ex D. Don) Lindl.
Incense-cedar	*Libocedrus decurrens* Torr.
Noble fir	*Abies procera* Rehd.
Pacific silver fir	*Abies amabilis* (Dougl.) Forbes
Port-Orford-cedar	*Chamaecyparis lawsoniana* (A. Murr.) Parl.
Sitka spruce	*Picea sitchensis* (Bong.) Carr
Sugar pine	*Pinus lambertiana* Dougl.
Western hemlock	*Tsuga heterophylla* (Raf.) Sarg.
Western redcedar	*Thuja plicata* Donn
Western white pine	*Pinus monticola* Dougl. ex D. Don

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Old-growth coniferous forests differ significantly from young-growth forests in species composition, function (rate and paths of energy flow and nutrient and water cycling), and structure. Most differences can be related to four key structural components of old growth: large live trees, large snags, large logs on land, and large logs in streams. Foresters wishing to maintain old-growth forest ecosystems can key management schemes to these structural components.

Keywords: Ecosystems, old-growth stands, stand composition, stand structure, Douglas-fir, *Pseudotsuga menziesii*, western hemlock, *Tsuga heterophylla*.

The **Forest Service** of the U.S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.

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April 1981

Influence of Forest and Rangeland Management on Anadromous Fish Habitat in Western North America

EFFECTS OF MINING

SUSAN B. MARTIN AND WILLIAM S. PLATTS

USDA FOREST SERVICE
ANADROMOUS FISH HABITAT
PROGRAM

U.S. Department of Agriculture Forest Service
Pacific Northwest Forest and Range Experiment Station

ABSTRACT

Methods of mining and the effects on aquatic ecosystems of mine-caused sediment, changes in pH, and toxic heavy metals are described.

KEYWORDS: Mining methods, aquatic ecosystems, sediment production, toxicity, fish habitat, anadromous fish.

USDA FOREST SERVICE
General Technical Report PNW-119

INFLUENCE OF FOREST AND RANGELAND MANAGEMENT ON ANADROMOUS FISH HABITAT IN WESTERN NORTH AMERICA

William R. Meehan, Technical Editor

8. Effects of Mining

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Boise, Idaho

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Forest Service, U.S. Department of Agriculture, Portland, Oregon

PREFACE

This is one of a series of publications summarizing knowledge about the nfluences of forest and rangeland management on anadromous fish habitat in estern North America. This paper addresses the effects of mining on anadromous ish habitat. Our intent is to provide managers and users of the forests and angelands of Western North America with the most complete information available or estimating the consequences of various management alternatives.

In this series of papers, we summarize published and unpublished reports and ata as well as observations of resource scientists and managers. These ompilations should be valuable to resource managers in planning uses of forest nd rangeland resources, and to scientists in planning future research. The xtensive lists of references serve as a bibliography on forest and rangeland esources and their uses.

Previous publications in this series include:

1. "Habitat requirements of anadromous salmonids," by D. W. Reiser and T. C. Bjornn.

2. "Impacts of natural events," by Douglas N. Swanston.

4. "Planning forest roads to protect salmonid habitat," by Carlton S. Yee and Terry D. Roelofs.

11. "Processing mills and camps," by Donald S. Schmiege.

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INTRODUCTION

About one-third of the United States is public land. Of these 743.2 million acres (300 million hectares), about 68 percent are open to mining (Sheridan 1977).

Congress mandated, through the Multiple Use-Sustained Yield Act of 1976, that public lands be managed for multiple use. But the Mining Law of 1872 conflicts with this objective, because it guarantees a single use--mining--wherever a valuable mineral deposit is found. Thus, mining can usurp other resource uses, unless the land has been specifically withdrawn from mineral development. Although mining is one of the chief uses of public lands, it is not necessarily part of the land-use planning process.

METHODS OF MINING

Surface mining, the earliest form of mineral recovery, is the process of removing minerals on or near the soil surface after stripping vegetation and overburden (soil and rock covering). Strip mining is a form of surface mining that results in a long, continuous excavation bordered by one or two parallel waste piles (contour mining) or by a series of parallel waste piles (area mining). This method is generally used to recover deposits of coal, lignite, clay, phosphate, and gypsum.

Auger mining is drilling into side slopes. Auger diameters may be as great as 7 feet (2.1 m), with holes 200 feet (71 m) or more in length. This method is frequently used to remove coal where overburden is too thick to permit economic stripping. Combinations of strip and auger mining are routinely used in Appalachia where coal strata normally occur in horizontal planes.

In quarrying or open-pit mining, the open excavations may have several working levels or benches. This method is used where the overburden is limited in proportion to the commodity recovered. Pit mining is used for removal of limestone, copper, uranium, iron, stone, sand, and gravel.

Dredge mining, which uses bucket or suction equipment to extract minerals from under water or subsurface water, is used extensively to recover gold, sand, and gravel, and some beach sand deposits containing rare earths.

In hydraulic mining, soil is eroded by high-pressure water jets. This method was used extensively in western gold mining, and it is still used in sand mining in coastal areas and in gold and coal mining in some western States.

In underground or hardrock mining, tunnels and shafts are cut into the earth. Pollution often results from the mining and milling operations themselves, as well as from tailings ponds and waste dumps associated with the mine.

MINING AND AQUATIC POLLUTION

Mining can pollute the aquatic environment by producing sediment, changes in pH, toxic heavy metals, and alterations in stream channel and streamflow.

SEDIMENT PRODUCTION

Sediment accrues in streams naturally and at moderate levels can b a beneficial component of anadromous fish habitat. Major disruption of the system occurs when amounts of sediment become excessive, however (Platts and Megahan 1975). Deposition of excessiv fine sediment on the stream bottom eliminates habitat for aquatic insects reduces density, biomass, number, and diversity of aquatic insects; reduces the permeability of spawning gravels; and blocks the interchange of subsurface and surface waters (Cooper 1959, Vaux 1962, McNeil 1964, Koski 1966). Toxic heavy metals can precipitate on bedload sediment particles and remain in the aquatic environment to be released later (Funk et al. 1975). Stream microorganisms can feed on sediments containing organic material and lower the dissolved oxygen content of the water (University of Pittsburgh 1972).

Sediments also contain nutrients, such as nitrogen and phosphorous. Excessive nutrient levels can lead to blooms of undesirable algal and plankton species and killing of fish from depletion of oxygen (Becker and Thatcher 1973).

The effects of suspended sediment on the aquatic system are more direct. Photosynthesis may be reduced because of light reduction; fish migration may be affected (European Inland Fisheries Advisory Commission 1965); fish may not be able to feed under turbid conditions, resulting in smaller fish (Sykora et al. 1972); and suspended solids may interfere with efficient respiration of gilled animals (Coker 1968). Young salmonids are particularly susceptible to gill irritation caused by turbid water, which in turn exposes them to infection by fungi and bacteria.

Mining can produce significant sources of bedload sediment and cause suspended solids to enter aquatic ecosystems. Glancy (1973) found annual sediment yields of 620 to 7,600 tons/mi^2 (218 to 2 670 metric tons/km^2) from mined areas, whereas undisturbed areas yielded only 60 to 930 tons/mi^2 (21 to 326 metric tons/km^2). The recovery of a stream affected by manganese strip-mining operations was monitored by Cumming and Hill (1971). Six years were required for the stream to recover fully from the mining effects after mine closure. Turbidity was the most damaging pollutant measured. Branson and Butch (1971) also concluded that the most damaging pollutant in a strip mine area was not the acid mine drainage, but the high siltation and turbidity originating from erosion of the spoil banks. Research in Kentucky indicated that sediment yields from forested areas were increased 1,000 times as a result of strip mining (Musser 1963). During a 4-year period, the average annual sediment yield from spoil banks was 27,000 tons/mi^2 (8 900 metric tons/km^2), but from control areas it was estimated at only 25 tons/mi^2 (8 metric tons/km^2). In Appalachia, Spaulding and Ogden (1968) estimated that about 1 acre-foot (1 230 m^3) of sediment was produced by every 80 acres (30 ha) of disturbed land.

Collier et al. (1970) and Curtis (1973) also documented the increased bedload sediment and suspended solids from surface-mine areas. Mine waste piles, haulroads, tailings ponds, coal and ore stockpiles, and beneficiation plants were all sources of sediment. Collier et al. showed that a partially strip-mined watershed (6.4 percent of area) had an erosion rate of 5.9 tons/acre (13.1 metric tons/ha) as compared to 0.7 tons/acre (1.5 metric tons/ha) for an unmined area. Peak flows during large rainstorms contained suspended solid concentrations of over 46 000 mg/liter from an unprotected strip-mine area in an Appalachian watershed study (Curtis 1971). If adequate vegetative cover is not established, continual exposure of fresh spoil prolongs the production of acid, soluble salt, and sediment to the aquatic system (Walker 1952, Vogel 1971, Farmer et al. 1976).

Lack of vegetative cover can also affect the extent of heavy metal contamination. Exposing rock strata to weathering and erosion results in higher zinc, copper, nickel, and iron concentrations in receiving streams (Neckers and Walker 1952, Massey and Barnhisel 1971, Massey 1972). Curtis (1971) concluded that adverse effects on hydrology can subside within 6 months under some conditions, if vegetative cover is reestablished.

In a study of the sand and gravel industry, Newport and Moyer (1974) reviewed the effects of sediment on benthic and planktonic communities, and on population, reproduction, and species composition of fish. They concluded that although a precise maximum concentration of inorganic suspended solids had not been detrimental to fish, the following were good approximations of the potential effects of sediment:

0-25 mg/liter	no harmful effects on fish
25-100 mg/liter	good to moderate fish habitat
100-400 mg/liter	unlikely to support a good fishery
400 mg/liter and above	poor fisheries habit[illegible]

Maximum allowable concentrations of suspended solids in streams classified for trout cannot exceed 10 mg/liter in several States (Hill 1974).

Inorganic silt was the pollutant limiting populations of fish and bottom organisms in reclaimed and partially reclaimed streams after strip mining for manganese (Hill 1972). Complete reclamation of spoil areas reduced siltation and turbidity, allowing recovery of stream fauna.

CHANGES IN pH

Acid is a major pollutant from mine drainage. Acid mine drainage occurs when pyritic material in sulfurous ores, usually associated with mining coal and heavy metals, is oxidized to produce ferrous sulfate and sulfuric acid. This results in a pH range of 2.0-4.5 in receiving waters, levels toxic to many forms of aquatic life (Hill 1974). A favorable pH range for fish is generally from 6.5 to 8.7 (Environmental Protection Agency 1976). Although fish can exist for short periods at slightly above and below this range, a pH lower than 5.0 is generally unfavorable for fish populations (Spaulding and Ogden 1968).

Some of the potential damages to aquatic biota from acid pollution are:

- Elimination of sensitive species and proliferation of tolerant species,
- Direct acute effects,
- Reduction in density, biomass, and diversity of aquatic organisms,
- Increase in abnormal behavior,
- Reduction in reproductive capacity of adults and in viability of eggs and alevins.

At lower pH levels, the aquatic biota may be virtually eliminated. Katz (1969) found no viable fishery at pH 3.5 and below. The dominant macroinvertebrates were chironomids and Sialis sp., generally considered indicators of poor water quality. No caddisflies (Trichoptera), mayflies (Ephemeroptera), or stoneflies (Plecoptera)--the preferred foods for salmonids-- were present at this low pH.

Studies in Norway and Sweden indicated extinction of fish populations often resulted from chronic reproductive failure because of acidification-induced effects on sensitive developmental stages (Brungs et al. 1978). Acid stress (pH 4.0-5.0) also has caused fish mortality, by interfering with the physiological mechanisms regulating active ion exchange across gill membranes (Brungs et al. 1978).

Although sublethal levels of acidity are not cumulative in fish, Anthony (1971) considered pH 5.0 or below hazardous, because they reduce the ability of fish to detoxify other poisons. Fish are apparently able to eliminate heavy metals from their bodies to a certain extent, but when the heavy metal concentration becomes too great or the pH too low, this ability is impaired.

Healthy, unpolluted streams generally have moderate numbers and many species of organisms, but polluted areas have larger numbers of a single organism. With toxic wastes--such as pollution from mining--both number and diversity of organisms are reduced. In West Virginia, more species of insects and algae occurred in an unpolluted stream (pH 4.5 or higher) than in those areas polluted by acid (pH 2.8 to 3.8) (Warner 1971). Menendez (1978) found a reduction in benthic fauna in a West Virginia stream severely affected by acid mine water.

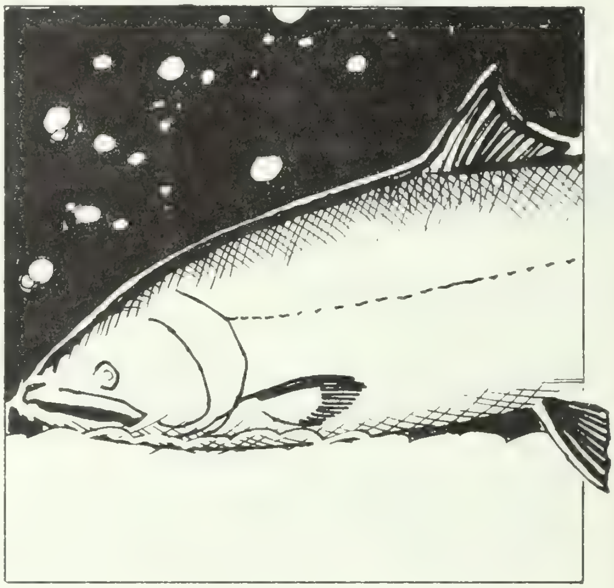
Low pH values may also affect behavior and reproduction of aquatic organisms. In a study on fathead minnows (Pimephales promelas Rafinesque), Mount (1973) found that fish behavior was abnormal and fish were deformed at pH 4.5-5.2. Abnormal eggs and reduced production and survival were observed at pH 5.9 and lower. A pH of 6.6 was marginal for vital life functions, but safe for continuous exposure.

Trojnar (1977) investigated the hatching response in eggs of brook trout (Salvelinus fontinalis (Mitchill)), incubated in gravel at pH 4.6 to 8.1, and observed the response of fry to different pH at emergence. Survival was zero when eggs were incubated at pH 8.1, and fry emerged at pH 4.0. With incubation and emergence at pH 4.6 to 5.0, fry survival increased 60 to 76 percent. This suggests an acclimation effect: fry incubated at lower, sublethal pH levels are less susceptible to acid mortality upon emergence than those reared under normal conditions (pH 6.7 to 8.2).

In addition, at low pH (pH<5.0), heavy metals that are complexed or coprecipitated with suspended solids and sediments may be released, adding another toxic pollutant to the aquatic system (Sorenson et al. 1977).

Acid drainage from large surface mines is not normally a problem in the West, as the alkaline soils in the region reduce the potential for acid drainage. Problems may arise from alkaline drainage, however. Iron is precipitated from oxygenated water as ferric hydroxide, which can smother fish eggs and cause gill irrigation (McKee and Wolf 1971). This precipitation is more complete in alkaline water than in acidic water (Ruttner 1963).

Oil-shale mining presents special alkaline pollution problems. Leachate from the shale is alkaline and high in total dissolved solids, with high concentrations of sodium, calcium, magnesium, and sulfates. Toxic amounts of aluminum may also be present in some shale. Elevated salinities from oil shale have also occurred in the lower Colorado River (Moore and Mill 1977).



TOXICITY OF HEAVY METALS

Dissolved heavy metals, commonly found in waters polluted by mine drainage, are toxic to the aquatic biota (Cairns and Scheier 1957; Tarzwell and Henderson 1960; Lloyd 1960, 1961a, 1961b; Lloyd and Herbert 1962; Mount and Stephan 1967). The actual metal concentration toxic to fish, however, is difficult to determine. Toxicity depends on fish species, age and stage of development (Lloyd 1960), water temperature (Chapman 1973), pH, dissolved oxygen concentration, total hardness, and synergism with other pollutants. In general, fish mortality results from exposure to high metal concentrations, but continuous low exposure produces chronic effects, such as behavioral changes, reproductive failure, or fry mortality (Chapman 1973). Both ultimately affect species survival.

Toxic metals commonly released by mining are arsenic, cadmium, cobalt, copper, iron, lead, manganese, mercury, nickel, and zinc. Individually, these metals may be toxic to aquatic biota, or they may exhibit a combined toxicity greater than that of the individual elements. Synergistic toxicity is common in waters polluted by heavy metals from mining. For example, in laboratory tests with a mixture of copper, cadmium, and zinc, a lethal threshold for fathead minnows was attained when each metal was present at a concentration of 40 percent or less of its individual lethal threshold (Eaton 1973).

Movements of fish in streams may be affected by the presence of heavy metals. Sprague (1964), in laboratory tests on Atlantic salmon (Salmo salar Linnaeus), found fish avoided copper and zinc at concentrations well below those found to cause mortality. Sprague reported metal concentrations as the "incipient lethal level" (ILL)--that level beyond which the organism could no longer survive for an indefinite period. Migrating Atlantic salmon avoided copper at 0.002 mg/liter (0.052 ILL) and zinc at 0.053 mg/liter (0.092 ILL). The maximum allowable concentration of copper recommended in waters inhabited by fish and other aquatic life is 0.02 mg/liter (McKee and Wolf 1971). For zinc, the concentration is 0.3 mg/liter, but for salmonids may be as low as 0.1 mg/liter (Rabe and Sappington 1970). These values are about ten times greater than those found to cause overt avoidance behavior in migrating fish, which illustrates how sensitive fish are to heavy metals.

Heavy-metal pollution may also have acute physiological effects on fish. Zitko and Carson (1977) found the ILL of zinc to juvenile Atlantic salmon varied from 0.15 to 1.0 mg/liter from fall through spring, with no detectable seasonal changes in water hardness, alkalinity, dissolved nitrogen, and humic acid concentration. The most sensitive period, as measured by the zinc ILL, coincided with the initial stages of the parr-smolt transformation and was, therefore, believed to be related to this physiological change. Studies by Lorz and McPherson (1977) also support this hypothesis.

Skidmore and Tovell (1972) demonstrated that acute exposure of rainbow trout (Salmo gairdneri Richardson) to zinc sulfate (40 mg/liter) caused a severe inflammatory reaction in the gill, with a separation of the epithelium outward from the pillar cells. This was followed by circulatory breakdown, tissue destruction, respiratory collapse, and death. Burton et al. (1972) confirmed that the major physiological change preceding death in acute toxicity studies with zinc was tissue hypoxia. The hypoxia was directly related to gill-tissue damage, which disrupts normal gas exchange at the gill surface.

The effect heavy-metal exposure has on aquatic organisms may be related to their physiological state. Boyce and Yamada (1977) investigated the difference in zinc susceptibility between juvenile sockeye salmon (Oncorhynchus nerka (Walbaum)) infected with the intestinal cestode Eubothrium salvelini (Schrank), and noninfected smolts. Under laboratory conditions, infected smolts were significantly more susceptible to 1 mg/liter of zinc than were noninfected smolts.

Chronic, low levels of heavy metals in water may cause long-term behavior changes in fish. Drummond et al. (1973) found behavioral changes in brook trout at concentrations as low as 0.005 mg/liter of copper. Studies on brook trout by McKim and Benoit (1971) showed that copper concentrations of 0.002 to 0.03 mg/liter had no effect on adult fish, but had a marked effect on survival and growth of alevins and juveniles. Zinc concentrations of 0.18 mg/liter greatly reduced egg production of the fathead minnow, a fish more resistant to heavy-metal toxicity than the salmonids (Brungs 1969). In the same study, Brungs found that fathead minnow growth was inhibited and mortalities occurred at 2.8 mg/liter of zinc. Holcombe et al. (1976) found that long-term exposure of brook trout to lead resulted in physiological changes. In three generations of fish exposed to lead concentrations ranging from 0.001 to 0.5 mg/liter, second- and third-generation trout developed spinal deformities (scoliosis). In addition, growth of third-generation trout was reduced.

Nonlethal levels of trace elements are subject to bioaccumulation in aquatic organisms (Krenkel 1973). In general, metal content in most tissues has been shown to decrease at higher trophic levels. Zinc concentrations may decrease in muscle from omnivorous species to predacious fish because of differences in metal content of the food they consume. An omnivorous fish feeds on detrital material, which likely contains high levels of metals. Among predacious fish, piscivores consume material that contains less metal than fish that feed primarily on invertebrates. Differences in metal content of tissue among fish species may also be related to fish size. Tissue levels of heavy metals, other than mercury, tend to decrease with an increase in size or age of fish (Bauer 1974).

Other aquatic organisms also show a response to the presence of heavy metal pollution. Some members of the aquatic midgefly family (Chironomidae) are tolerant of high copper concentrations--up to 2.2 mg/liter (Surber 1959). Some caddisfly larvae may be equally tolerant of heavy-metal pollution (Sprague et al. 1965). Most mayfly nymphs cannot survive in streams with heavy-metal concentrations far below those lethal to trout (McKee and Wolf 1971). For example, Warnick and Bell (1969) found 0.3 mg/liter of iron toxic to mayflies, stoneflies, and caddisflies. Fish populations, however, can tolerate iron concentrations up to 1.0 mg/liter (Ellis 1940). Enk and Mathis (1977) found higher cadmium and lead concentrations in sediments and aquatic insects than in fish in an Illinois stream. This suggests that the sediments acted as a sink for the metals, and bottom-feeding aquatic insects concentrated the metals.

The complex interactions of organisms in an aquatic system can also be influenced by the presence of heavy metals. Sodergren (1976) concluded that a reduction of invertebrate fauna in a Swedish stream polluted with cobalt resulted in a drastic reduction of juvenile Atlantic salmon.

STREAM CHANNEL AND STREAMFLOW ALTERATION

Stripping vegetation and dredging and channelizing streams can occur during mining operations. Such activities will result in increased erosion and sediment because of unstable streambanks and can lead to increased streamflows. Removal of vegetation often results in higher peak flows during runoff and lower base flows during low-flow periods. Reduction in surface-water area or streamflow may reduce the quantity and quality of habitat available to fish and other aquatic organisms (Moore and Mill 1977). Direct use of water in milling and mining operations may also decrease stream flows.

ABANDONED MINES

Pollution from abandoned, "orphan" mines can be as much of a problem as from mines that are active. Matter et al. (1978) found that sulfate, total hardness, and silt indices were elevated in streams draining abandoned mines in Virginia. Total abundance and taxonomic richness of fish and benthic invertebrate populations were reduced in streams draining orphan-mine areas, even 10 to 20 years after abandonment.

Researchers found that an old open-pit mine in Montana caused water quality problems in the upper Stillwater River even though operations ceased there in the early 1950's (Brown and Johnston 1976). Acid drainage continued to kill the native vegetation adjacent to the mine and to destroy the aquatic ecosystem in the river. The area also has high soil erosion and stream sedimentation resulting from the lack of vegetative cover. Highly acid conditions and concentrations of heavy metals in soils within the rooting zone aggravate reclamation problems (Johnston et al. 1975).

In studies of the abandoned Blackbird Mine in central Idaho, Farmer et al. (1976) found little vegetative regrowth on a low-grade mine-waste pile. Twenty years after mine closure, soil in the dump was still severely acidic (pH 3.0 to 4.0) and infertile. Extensive rehabilitation efforts were necessary to reestablish vegetation on the waste pile.

Platts et al. (1979), in another study of the Blackbird Mine, found that heavy-metal concentrations in the Panther Creek watershed remained high after mine closure. Mean concentrations of cobalt and copper in polluted streams were toxic to aquatic biota, and levels of iron, lead, and manganese were higher than in streams draining unmined areas. Water samples from sites downstream from the mined area had consistently lower pH values than those upstream. The stream channel below the mined areas had high concentrations of fine sediment even after mine closure--the result of erosion from unreclaimed waste piles and tailings ponds. Sediment and heavy-metal pollutants completely eliminated runs of chinook salmon (Oncorhynchus tshawytscha (Walbaum)) and steelhead trout (Salmo gairdneri Richardson) that occupied the drainage before mining (Platts 1972).

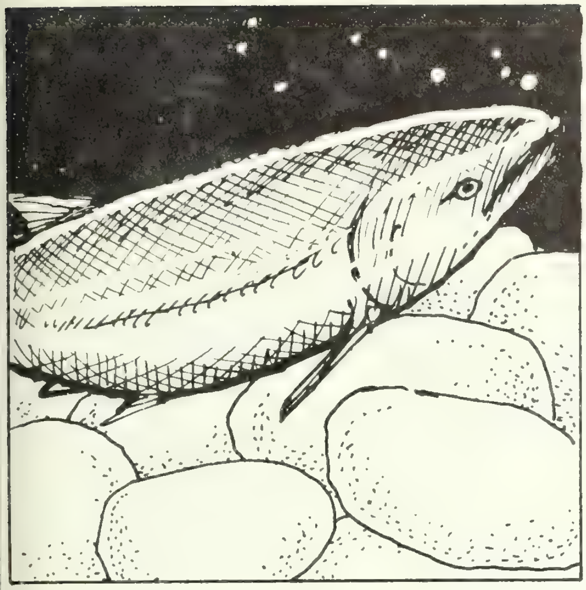
DISCUSSION

The effect of mining pollution on aquatic environments has been significant. When no reclamation efforts are made, the effects of mining on streams may be prolonged long after active operations cease.

State and Federal governments are becoming more active in regulating mining activities to conserve and protect natural resources. In most western States, a plan outlining potential environmental damage and proposed rehabilitation is required before permission to mine a site is granted. Posting of a reclamation performance bond to cover damages is also necessary.

Adequate Federal and State water-quality standards to protect aquatic environments now exist in most areas. Manpower limitations, however, make monitoring and enforcement of these regulations difficult. Idaho, for example, has only one land-reclamation specialist. This person must rely on help from other agencies to supplement information on whether mine operations are in compliance.

Although future protection of the aquatic habitat in mine areas looks promising, more funds are necessary to guarantee adequate safeguards. More research in developing reclamation measures is also needed. The aquatic environment should be treated as the important resource that it is.



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WILDLIFE HABITATS IN MANAGED RANGELANDS—THE GREAT BASIN OF SOUTHEASTERN OREGON

PLANT COMMUNITIES AND THEIR IMPORTANCE TO WILDLIFE

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ABSTRACT

Plant communities in the Great Basin of southeastern Oregon are described, and a field key is provided. The value of a plant community's vertical and horizontal structure and the seasonal availability of its forage are examined in relation to wildlife habitat in managed rangelands. Further, the importance of individual and combined plant communities to wildlife in managed rangelands is discussed, and management alternatives are presented.
KEYWORDS: Communities (plant), range management, wildlife habitat.

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This publication is part of the series **Wildlife Habitats in Managed Rangelands — The Great Basin of Southeastern Oregon**. The purpose of the series is to provide a range manager with the necessary information on wildlife and its relationship to habitat conditions in managed rangelands in order that the manager may make fully informed decisions.

The information in this series is specific to the Great Basin of southeastern Oregon and is generally applicable to the shrub-steppe areas of the Western United States. The principles and processes described, however, are generally applicable to all managed rangelands. The purpose of the series is to provide specific information for a particular area but in doing so to develop a process for considering the welfare of wildlife when range management decisions are made.

The series is composed of 14 separate publications designed to form a comprehensive whole. Although each part will be an independent treatment of a specific subject, when combined in sequence, the individual parts will be as chapters in a book.

Individual parts will be printed as they become available. In this way the information will be more quickly available to potential users. This means, however, that the sequence of printing will not be in the same order as the final organization of the separates into a comprehensive whole.

A list of the publications in the series, their current availability, and their final organization is shown on the inside back cover of this publication.

Wildlife Habitats in Managed Rangelands — The Great Basin of Southeastern Oregon is a cooperative effort of the USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, and United States Department of the Interior, Bureau of Land Management.

Introduction

Our purpose is to describe the major plant communities and examine the importance of their structure and species composition to wildlife. Plant communities here are directly related to the wildlife covered in the other chapters and can be used in developing management plans based on characteristics and potential of the plant community. We did not cover some northern Great Basin rangeland communities because they are rare, small in total area, or information is not available.

Great Basin rangelands in southeastern Oregon support a wide variety of plant communities, dominated by grasses, shrubs, or trees ranging from conifers to deciduous and evergreen hardwoods. Predominant are big sagebrush communities.[1] Tree-dominated and true grassland communities constitute the least common types. True grasslands occur as meadows, relict stands of valley bottom bunchgrass, and subalpine bunchgrass types.

Tree-dominated communities occur primarily at elevations above the sagebrush steppe, except willow and cottonwood communities of low-elevation riparian zones. Quaking aspen is primarily restricted to mountain riparian zones, such as streams, seeps, springs, ponds, or lakes (fig. 1). With the exception of relict stands of ponderosa pine (Packard 1972) or white fir (Hansen 1956), curlleaf mountainmahogany requires the most moisture of the dry-land tree types in the high desert mountains. Western juniper grows just below curlleaf mountainmahogany and mixes with it in transition zones. These tree-dominated communities are adjacent to and above the shrub zone.

Big sagebrush, including several subspecies, is dominant among the shrub communities. Other significant tall shrub communities include black greasewood, squaw apple, Bolander silver sagebrush, and mountain silver sagebrush. Short shrub communities include shadscale saltbush, and stiff, low, early low, black, and cleftleaf sagebrushes.

[1]Common and scientific names and plant symbols are from Garrison et al. (1976) and are listed in the appendix.

The terms "stand" and "community" are used as suggested by international agreements on terminology (Küchler 1964, Mueller-Dombois and Ellenberg 1974). The specific unit of vegetation observed in the field is called a vegetation stand or stand (coenosis). The generalized, abstract unit of vegetation analogous to an "average" of a group of similar stands is a plant community or vegetation type. A plant community with a "definite flora, uniform habitat, and physiognomy" is called an association (Mueller-Dombois and Ellenberg 1974, p. 174).

Plant communities presented here are compared with Küchler's (1964) vegetation types in table 1. Küchler has one major vegetation type for each listing, which represents the major physiognomy (general aspect and visual character) of a region. Küchler omits other similar vegetation types less extensive in occurrence and less noticeable or refers to them as inclusions because his treatment of vegetation throughout the conterminous United States is so extensive. Table 1 shows single vegetation types of Küchler's related to a number of vegetation types used in this publication. The best example is Küchler's (1964) "sagebrush steppe"—the big sagebrush-bearded bluebunch wheatgrass vegetation type. We recognize 11 vegetation types dominated by sagebrush within Küchler's (1964) "sagebrush steppe." The Wyoming big sagebrush/bunchgrass vegetation type described here is probably the only one relating directly to it since it is considered the most common sagebrush of the high desert in Oregon (Winward 1980).

Subtle variations in an environment give rise to different subordinate plant species in communities. These "characteristic" and "differentiating" species (Mueller-Dombois and Ellenberg 1974) are useful indicators of site potential. For example, the mountain big sagebrush/bunchgrass community encompasses stands containing either Thurber needlegrass, western needlegrass, or needle-andthread. These grasses are generally subordinate to bearded bluebunch wheatgrass and reflect an increasing sandiness of the soil profile. Recognition of these three variations

Figure 1.—Elevation and site relationships among dominant plant species in the Great Basin of southeastern Oregon. Plant symbols are from Garrison et al. (1976). AGSP = *Agropyron spicatum*; ARAR = *Artemisia arbuscula*; ARCA = *Artemisia cana*; ARL02 = *Artemisia longiloba*; ARN02 = *Artemisia nova*; ARRI = *Artemisia rigida*; ARSP = *Artemisia spinescens*; ARTR2 = *Artemisia tripartita*; ARTRT = *Artemisia tridentata* subsp. *tridentata*; ARTRV = *Artemisia tridentata* subsp. *vaseyana*; ATCO = *Atriplex confertifolia*; CARU = *Calamagrostis rubescens*; CELE = *Cercocarpus ledifolius*; CEVE = *Ceanothus velutinus*; DISTI = *Distichlis* sp.; ELCI = *Elymus cinereus*; FEID = *Festuca idahoensis*; GRSP = *Grayia spinosa*; JUOC = *Juniperus occidentalis*; MURI = *Muhlenbergia richardsonis*; PIPO = *Pinus ponderosa*; POSA3 = *Poa sandbergii*; POTR = *Populus tremuloides*; PREM = *Prunus emarginata*; SAVE2 = *Sarcobatus vermiculatus*; SIHY = *Sitanion hystrix*; SYOR = *Symphoricarpus oreophilus*.

Table 1—Comparison of the plant communities with potential natural vegetation by Küchler (1964)

Natural vegetation as described by Küchler (1964)	Plant communities in this publication
37 mountainmahogany-oak scrub (similar position—not equal)	Curlleaf mountainmahogany/mountain big sagebrush/bunchgrass
	Curlleaf mountainmahogany/mountain snowberry/grass
	Curlleaf mountainmahogany/pinegrass
	Curlleaf mountainmahogany/Idaho fescue
	Curlleaf mountainmahogany/bearded bluebunch wheatgrass-Idaho fescue
No provision	Squaw apple/bunchgrass
55 sagebrush steppe (with juniper)	Western juniper/big sagebrush/bearded bluebunch wheatgrass
	Western juniper/big sagebrush/Idaho fescue
55 sagebrush steppe	Basin big sagebrush/bunchgrass
	Wyoming big sagebrush/bunchgrass
	Mountain big sagebrush/bunchgrass
	Threetip sagebrush/bunchgrass
	Bolander silver sagebrush/bunchgrass
	Mountain silver sagebrush/bunchgrass
	Stiff sagebrush/bunchgrass
	Low sagebrush/bunchgrass
	Cleftleaf sagebrush/bunchgrass
	Early low sagebrush/bunchgrass
	Black sagebrush/bunchgrass
40 saltbush-greasewood	Black greasewood/grass
	Shadscale saltbush/bunchgrass
No provision	Riparian
No provision	Permanently wet meadows
	Seasonally wet meadows
No provision	Quaking aspen/mountain big sagebrush
	Quaking aspen/grass
No provision	Subalpine big sagebrush/bunchgrass
52 alpine meadows and barren (similar—not equal)	Subalpine bunchgrass

within the community should help managers of wildlife and livestock. The associated changes in soil texture[2] and plant phenology are important to programs designed to maintain suitable habitat for animals and to increase production of forage.

[2]Soil nomenclature and definitions are from "Soil Survey Manual" (Soil Survey Staff 1951).

PLANT AND COMMUNITY STRUCTURE

Most animal species are more narrowly adapted to plant structure for thermal and hiding cover than they are to plant species for food. For example, mule deer and black-tailed jackrabbits use a wide variety of forage species (Hill 1956, Ingles 1967, Kufeld et al. 1973); but a specific structure of trees or shrubs (fig. 2) is required to fulfill their thermal or hiding cover requirements (Anthony 1928, Thomas et al. 1979a). The sage sparrow has seed and insect food available in many plant communities, but a specific shrub structure is required to provide hiding cover and suitable nesting sites (Gabrielson and Jewett 1940, Miller 1968). The overhanging or umbrellalike structure of bunchgrass provides both hiding and thermal cover for birds, such as the lark sparrow in the open bunchgrass communities (fig. 3).

Figure 2.—Big sagebrush provides important thermal cover for small mammals (Robert R. Kindschy photograph).

Figure 3.—A, arrow at the base of a bunchgrass points to the nest of a lark sparrow. B, the nest is hidden from predators and is protected from sun and wind in an open stand of grass by the overhanging blades of grass (Chris Maser photograph).

Shrub structure is variously altered from browsing by different animals and at different intensities (fig. 4). Antelope bitterbrush, for instance, when severely browsed produces a crown that appears to be structurally different, depending on type and intensity of use (Hormay 1943). This species also occurs throughout its range in different structural forms because of what appear to be genetically distinct populations (Alderfer 1976, Nord 1965).

A B C

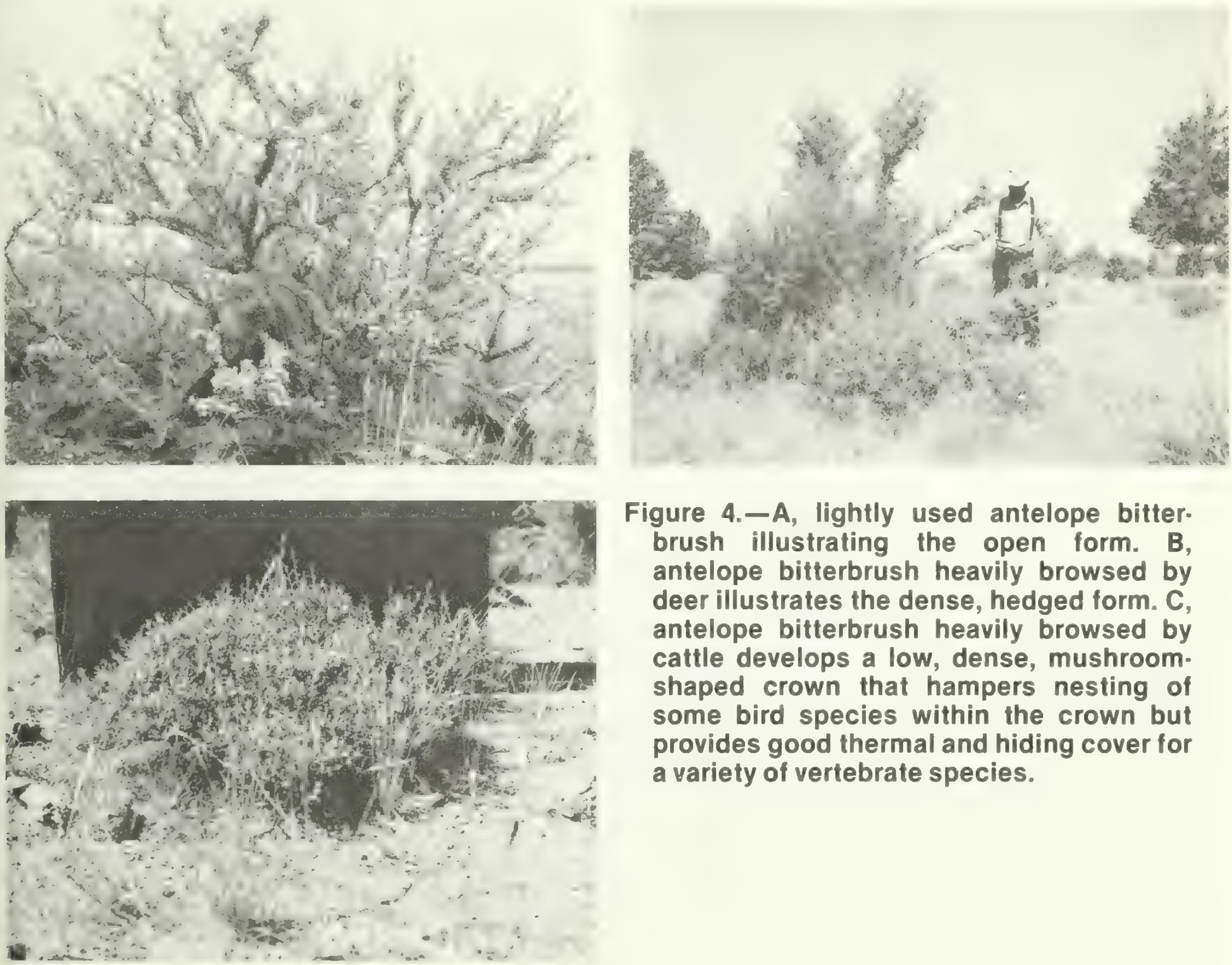

Figure 4.—A, lightly used antelope bitterbrush illustrating the open form. B, antelope bitterbrush heavily browsed by deer illustrates the dense, hedged form. C, antelope bitterbrush heavily browsed by cattle develops a low, dense, mushroom-shaped crown that hampers nesting of some bird species within the crown but provides good thermal and hiding cover for a variety of vertebrate species.

The structural diversity of rangeland communities relates directly to wildlife diversity: the greater the structural diversity, the greater the wildlife diversity (fig. 5). Exceptions may occur where a mosaic of diverse stands is on a scale too small to meet the home range needs of a species that requires large blocks of uniform vegetation (Thomas et al. 1978, 1979c).

Figure 5.—Cliffs, talus, sagebrush, juniper, seasonally and permanently wet meadows, and riparian vegetation provide habitat for a wide variety of wildlife in the western edge of the Great Basin.

Plant communities contain both vertical and horizontal structural elements. At least three vertical vegetative layers—herbaceous, shrub, and tree (fig. 6)—are provided by western juniper communities in high desert rangelands. MacArthur and MacArthur (1961) considered vertical layers of vegetation critical to diversity of avian species. Thomas et al. (1977) examined each 5-foot layer of vegetation from shrubs to the tops of trees and found that

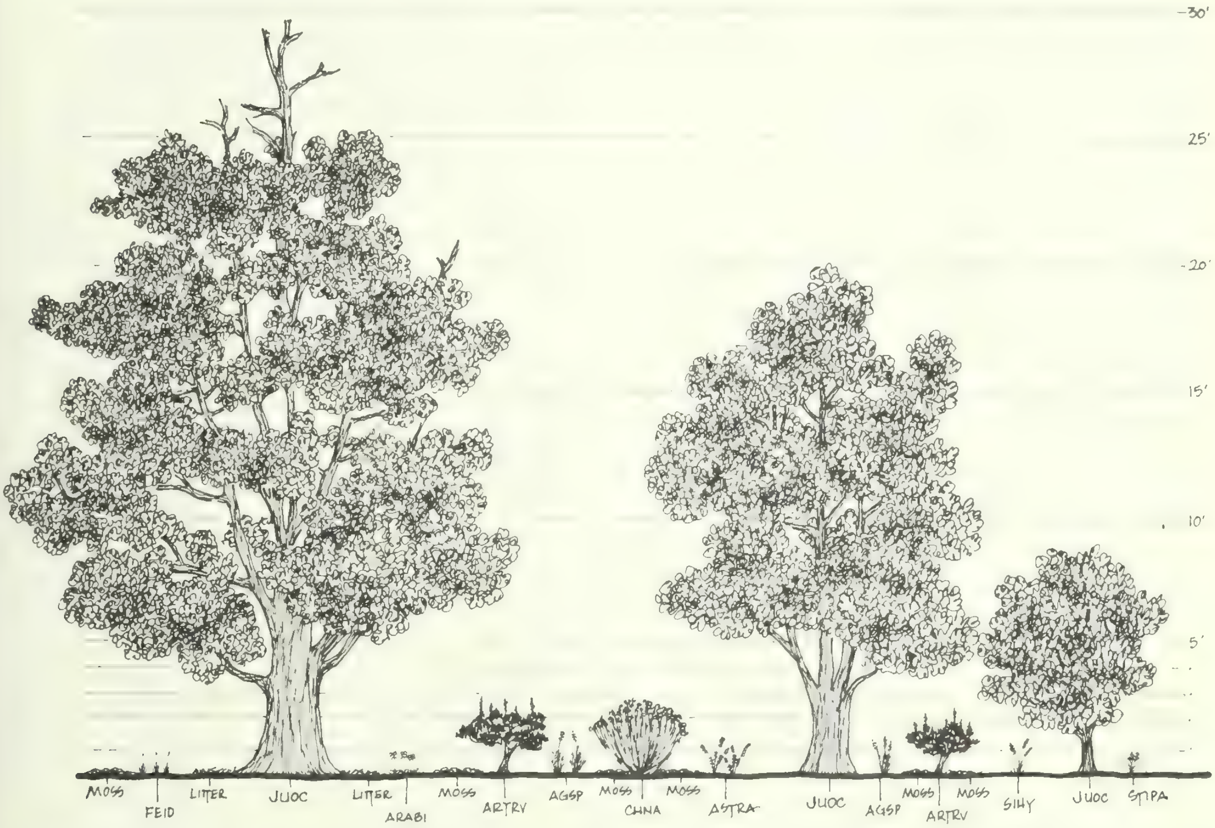

Figure 6.—This tree-shrub-grass community illustrates the structural variety present and the high vertical diversity in some communities of the high desert. Plant symbols are from Garrison et al. (1976). AGSP = *Agropyron spicatum*; ARABI = *Arabis* sp.; ARTRV = *Artemisia tridentata* subsp. *vaseyana*; ASTRA = *Astragalus* sp; CHNA = *Chrysothamnus nauseosus*; FEID = *Festuca idahoensis*; JUOC = *Juniperus occidentalis*; SIHY = *Sitanion hystrix*; STIPA = *Stipa* sp.

different species of birds were significantly correlated with different vertical layers in both coniferous and deciduous vegetation. Horizontal diversity, on the other hand, deals primarily with stands of different plant communities or different stages within plant communities that are close together (fig. 7). For example, optimum spacing between stands of big sagebrush and crested wheatgrass for black-tailed jackrabbits requires that the wheatgrass openings be no larger than 600 meters (1,900 ft) across (Westoby and Wagner 1973), because most use of wheatgrass occurs within 300 meters (985 ft) of the type edge. This illustrates how the size of two adjacent communities can result in optimum habitat for a particular animal species.

Rangelands of the desert basins, uplands, and mountains are limited in their complement and acreage of tree communities and true (climax) grasslands. The abundant shrub communities are predominantly big sagebrush. In the enhancement of both livestock range and wildlife habitat, a mixture of communities in proper juxtaposition and of optimum stand size provides a more suitable environment than large uniform areas of seeded grasslands or dense shrublands. Tree communities, such as western juniper and curlleaf mountain-mahogany, provide valuable thermal and hiding cover for wild ungulates (deer, pronghorn, bighorn sheep) and other species of wildlife, as well as important shading areas for livestock in the summer.

These communities with an open tree cover, besides being good wildlife habitat, produce an ideal opportunity for livestock to obtain much needed shade close to forage. McIlvain and Shoop (1971) studied the use of shade by cattle in the southern Great Plains and found that summer-long gains by yearling Hereford steers increased 9 kilograms (19 lb) per head when shade was available. They also found that shade was nearly as effective as the location of water and supplemental feed in distributing use by cattle. Advantages of shade for livestock, then, are threefold: increased weight gain, increased forage supply, and more uniform range conditions. These advantages also apply to ungulate wildlife.

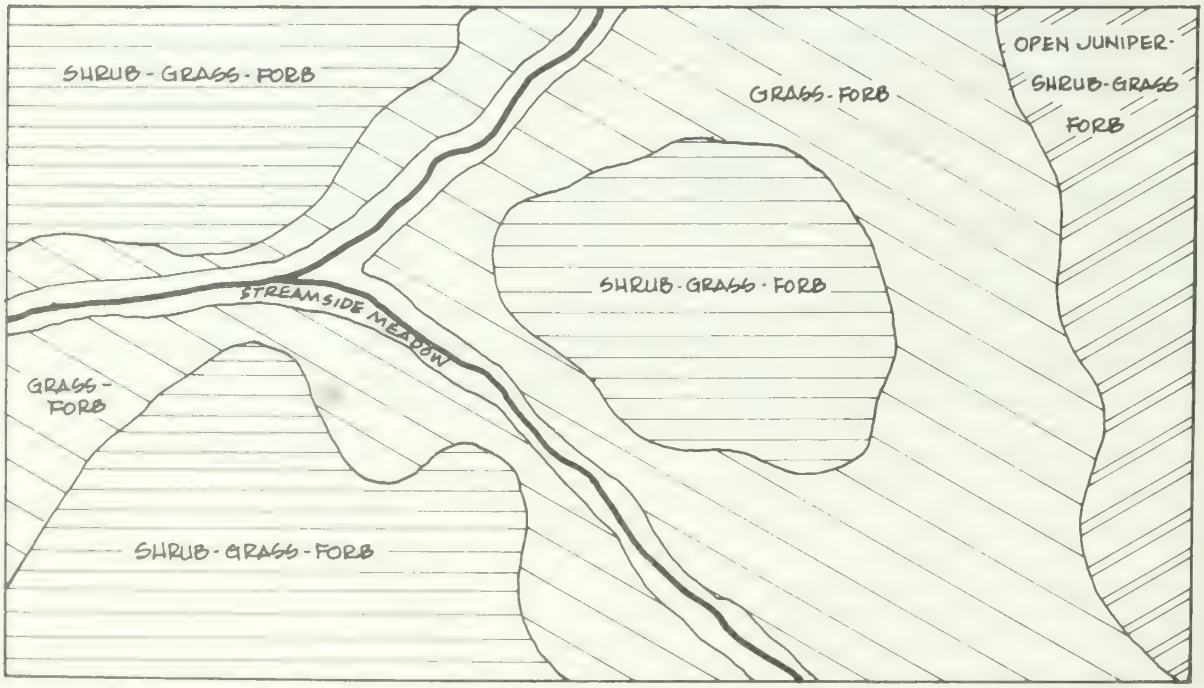

Figure 7.—A variety of habitats produces a variety of wildlife. A mosaic of plant communities of appropriate sizes and shapes maximizes edge and provides a wide selection of forage and cover species.

AVAILABILITY OF FORAGE

Forage availability of high desert plant communities varies annually and seasonally (fig. 8). Annual herbaceous species are available as green forage in early spring but dry rapidly and provide only dry material by late spring. Most perennial herbaceous species are generally available from midspring to midsummer, whereas deciduous shrub and tree species usually provide their most nutritious forage from midspring through late summer. Evergreen and deciduous shrub and tree forage is available throughout the year, although nutritional value peaks in the early growing season. Annual and perennial herbaceous species produce nutritious regrowth after fall rains. Although production varies among years, regrowth is usually available throughout the winter, particularly on south-facing exposures.

Controlled seasonal use is the key to coordinated use of the same range by livestock and wild ungulates. Controlled livestock use of perennial grasses can produce a stubble height of some plants short enough to allow wild ungulates to reach green regrowth that otherwise would be unavailable to them. Also, important winter foraging areas of wild ungulates can be enhanced by preventing livestock from grazing after fall rains have produced herbaceous regrowth.

PLANT COMMUNITY GROUPS

The array of plant communities listed in the following key and later described in detail can be dealt with individually in management. Depending on the user's objective, however, simplified groupings of these communities may be made (table 2). A criterion for grouping might be that the combined communities have equivalent values for livestock or for a featured wildlife species; or the communities in the group would react in an equivalent way to a specific management program (Leckenby 1978a). The rationale for grouping plant communities and examples of the relationships of terrestrial vertebrates to such groups will be presented in another chapter in this series, "The Relationship of Terrestrial Vertebrates to the Plant Communities."

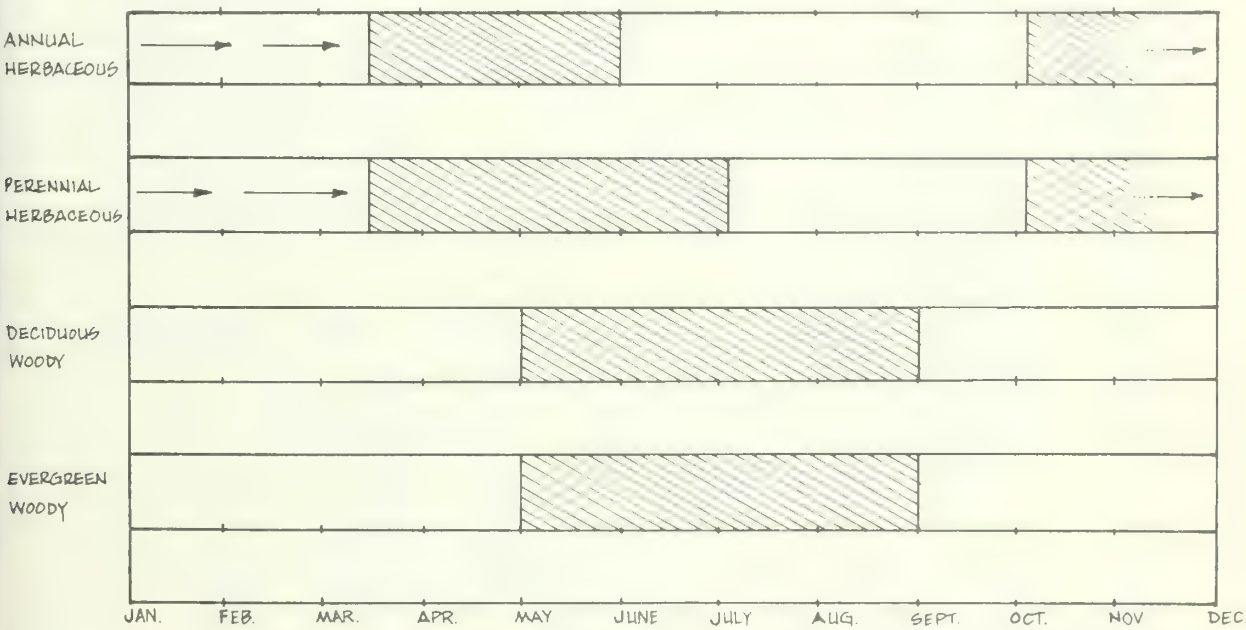

Figure 8.—Completely shaded blocks indicate the season of greatest productivity and nutritional value for forage plants. Partially shaded blocks with arrows indicate nutritious fall regrowth.

Table 2—Plant communities grouped by similarity of structure and selected structural and site characteristics[1]

Community number	Page number	Community	Structurally similar	Maximum number of vertical layers	Maximum height; meters (feet)	Ungulate thermal cover	Ungulate hiding cover	Ungulate forage	Small vertebrate thermal cover	Small vertebrate hiding cover	Small vertebrate forage	Elevational range; meters (feet)	General soil depth[1] and other notes
1	17	Riparian		4	25.0 (80)	X	X	X	X	X	X	All	Highly variable in soil depth and stoniness
2	17	Quaking aspen/grass		4	21.0 (70)	X	X	X	X	X	X	1 525-2 134 (5,000-7,000)	Moderately deep to deep
3	18	Quaking aspen/mountain big sagebrush		4	12.0 (40)	X	X	X	X	X	X	1 525-2 134 (5,000-7,000)	Moderately deep to deep
4	20	Curlleaf mountainmahogany/mountain big sagebrush		3	7.0 (23)	X	X	X	X	X	X	1 600-1 950 (5,250-6,400)	Shallow to moderately deep, stoniness variable
5	22	Curlleaf mountainmahogany/mountain snowberry											
6	22	Curlleaf mountainmahogany/Idaho fescue		2	7.0 (23)	X	X	X	X	X	X	1 600-1 700 (5,250-5,575)	Moderately deep; stoniness variable
7	22	Curlleaf mountainmahogany/bearded bluebunch wheatgrass Idaho fescue											
8	24	Curlleaf mountainmahogany/pinegrass										1 750-1 920 (5,750-6,300)	Moderately shallow; stoniness highly variable
9	25	Western juniper/big sagebrush/bearded bluebunch wheatgrass		4	10.0 (33)	X	X	X	X	X	X	777-1 450 (2,550-4,750)	Shallow to moderately deep; stoniness variable
10	25	Western juniper/big sagebrush/Idaho fescue											
11	31	Basin big sagebrush/bunchgrass		3	2.4 (8)	X	X	X	X	X	X	Below 2 140 (7,000)	Moderately deep to deep; stoniness variable. Silver sagebrush flooded in spring
12	35	Mountain big sagebrush bunchgrass										1 070-2 900 (3,500-9,500)	
13	35	Subalpine big sagebrush bunchgrass										1 070-2 900 (3,500-9,500)	
14	37	Wyoming big sagebrush/bunchgrass										Below 1 980 (6,500)	
15	38	Threetipped sagebrush bunchgrass										915-1 830 (3,000-6,000)	
16	40	Bolander silver sagebrush bunchgrass										1 680-2 440 (5,500-8,000)	
17	40	Mountain silver sagebrush/bunchgrass										1 680-2 440 (5,500-8,000)	

Table 2—Plant communities grouped by similarity of structure and selected structural and site characteristics[1] (Continued)

Community number	Page number	Community	Structurally similar	Maximum number of vertical layers	Maximum height: meters (feet)	Ungulate thermal cover	Ungulate hiding cover	Ungulate forage	Small vertebrate thermal cover	Small vertebrate hiding cover	Small vertebrate forage	Elevational range: meters (feet)	General soil depth/ and other notes
18	42	Stiff sagebrush bunchgrass	}	2	4 (1.3)	—	—	X	X	X	X	915- (3,000- 2 134 7,000)	Very shallow and mostly very stony over a layer restricting root growth, saturated in spring
19	44	Low sagebrush bunchgrass										915- (3,000- 2 745 9,000)	
20	44	Cleftleaf sagebrush bunchgrass										1 525- (5,000- 2 745 9,000)	
21	47	Black sagebrush bunchgrass										1 220- (4,000- 2 745 9,000)	
22	47	Early low sagebrush bunchgrass										1 830- (6,000- 2 440 8,000)	
23	48	Squaw apple bunchgrass		3	1.5 (5)	X	X	X	X	X	X	760- (2,500- 1 525 5,000)	Moderately deep to deep
24	49	Black greasewood bunchgrass		2	1.5 (5)	X	X	X	X	X	X	600- (2,000- 1 525 5,000)	Deep, flooded in spring
25	51	Shadscale saltbush bunchgrass		2	5 (1.6)	—	—	X	X	X	X	760- (2,500- 1 525 5,000)	Moderately deep, no apparent layer restricting root growth
26	52	Meadow, seasonally wet		1		—	—	X	X	X	X	All	Deep, saturated to flooded in spring, dry in summer and fall
27	54	Meadow, permanently wet		1		—	—	X	X	X	X	All	Deep, saturated to flooded in spring; perennially wet
28	55	Subalpine bunchgrass		1	3 (1.2)	—	—	X	X	X	X	2 439- (8,000- 2 900 9,500)	Shallow to deep, stoniness variable

X = present

[1]Very shallow = less than 25 centimeters (10 inches), shallow = 26 to 50 centimeters (10 to 20 inches), moderately deep = 51 to 125 centimeters (20-49 inches), and deep = more than 126 centimeters (49 inches)

Key to Plant Communities

CONSTRUCTION OF KEY

The plant communities are identified in a dichotomous key by descriptive vegetation and site characteristics easily recognized in the field. Groups of communities are separated on broad characteristics, such as trees vs. no trees, broadleaf trees vs. coniferous trees, shrubs vs. no shrubs, and so forth. Here we consider curlleaf mountainmahogany a tree. Site information, such as elevation or topography, is used as an aid in distinguishing communities or groups of communities. Separation within community groups may be based on vegetative differences among dominant species, such as anatomical variations in leaves alone or in combination with differences in form or height.

Some native communities are not covered. Some stands will not key to a community because of their early stage of succession. In stands where community identification is difficult, users should refer to the section, "successional vegetation."

KEY

The general riparian zone will be identified here rather than within the structure of the key because there is insufficient information from which to develop a multiple community key section: It is a zone with communities immediately adjacent to water, that require large amounts of free or unbound water, that may be dominated by trees, shrubs, or grasses, and that may be multilayered — (RIPARIAN ZONE COMMUNITIES, page 17).

Page

1a Communities with tree cover (tree communities not in key; see "SUCCESSIONAL VEGETATION" page 55)

2a Cover dominated by broadleaf trees

3a Tree cover dominated by quaking aspen

4a Shrub cover of mountain big sagebrush common to abundant (QUAKING ASPEN/MOUNTAIN BIG SAGEBRUSH) 18

4b Shrub cover sparse to absent (QUAKING ASPEN/GRASS) 17

3b Tree cover dominated by curlleaf mountainmahogany

5a Shrub cover common

6a Shrubs primarily mountain big sagebrush (CURLLEAF MOUNTAINMAHOGANY/MOUNTAIN BIG SAGEBRUSH/BUNCHGRASS) 20

6b Shrubs primarily mountain snowberry (CURLLEAF MOUNTAINMAHOGANY/MOUNTAIN SNOWBERRY/GRASS) 22

5b Shrub cover sparse to absent

7a Understory primarily bunchgrass

8a Grass layer obviously dominated by Idaho fescue (CURLLEAF MOUNTAINMAHOGANY/IDAHO FESCUE). 22

8b Grass layer not obviously dominated by Idaho fescue; grass a codominant mixture of bearded bluebunch wheatgrass and Idaho fescue (CURLLEAF MOUNTAINMAHOGANY/BEARDED BLUEBUNCH WHEATGRASS-IDAHO FESCUE) . . . 22

7b Understory not primarily bunchgrass; grass predominantly pinegrass (CURLLEAF MOUNTAINMAHOGANY/PINEGRASS) . . . 24

2b Cover dominated by coniferous trees; dominant tree western juniper with a shrub layer dominated by big sagebrush

9a Grass cover dominantly bearded bluebunch wheatgrass (WESTERN JUNIPER/BIG SAGEBRUSH/BEARDED BLUEBUNCH WHEATGRASS) 25

9b Grass cover dominantly Idaho fescue (WESTERN JUNIPER/BIG SAGEBRUSH/IDAHO FESCUE). 25

1b Communities without tree cover

10a Communities with shrub cover dominant; grasses and forbs mostly native (shrub communities not in key; see "SUCCESSIONAL VEGETATION" page 55)

11a Dominant mature[3] shrubs taller than 5 decimeters (20 inches)

12a Dominant shrub a sagebrush species[4]

13a Dominant shrub with persistent (overwintering), entire (leaf edges smooth), and lance-shaped leaves

14a Leaves of dominant shrub silver-gray, plants in internally drained basins with seasonal flooding; associated herbaceous vegetation usually sparse; soil alkaline and extremely clayey (BOLANDER SILVER SAGEBRUSH/BUNCHGRASS). . . . 40

[3]Mature sagebrush considered at least 20 years old by count of annual rings or xylem layers of main stem (Winward 1980). This should also be the guide for other shrub species.

[4]Sagebrush and attendant site characteristics from Winward (1980) and Winward and Tisdale (1977).

14b Leaves of dominant shrub green-gray, plants along margins of streams or meadows; associated herbaceous vegetation floristically rich and highly productive; variable soils (MOUNTAIN SILVER SAGEBRUSH/BUNCHGRASS). . . .

13b Dominant shrubs with persistent lobed and wedge-shaped leaves

15a Dominant shrub uneven topped, with flowering shoots (inflorescences) arising throughout the crown (bottom to top); branches appear as upright feathery sprays

16a Mature shrubs greater than 100 centimeters (40 inches) tall; leaf margins straight, forming a tapered wedge; common big sagebrush community of valley bottoms and foothills on deep, well-drained soils (BASIN BIG SAGEBRUSH/BUNCHGRASS) . . . .

16b Mature shrubs less than 100 centimeters (40 inches) tall; leaf margins flare outward, forming a bell-shaped wedge; sagebrush on dry sites commonly below 1 830 meters (6,000 ft) and on moderately deep, well-drained soils (WYOMING BIG SAGEBRUSH/BUNCHGRASS) . . . .

15b Dominant shrubs even topped with flowering shoots (inflorescences) arising from the upper portion of the crown and extending above the foliage

17a Dominant shrub with leaf margins belled outward; flower stalks absent, flowers attached directly to main stem of flowering shoot (inflorescence spicate) or flower stalks present but unbranched (inflorescence racemose); widespread through the high desert steppe (LOW SAGEBRUSH/BUNCHGRASS) . . . .

17b Dominant shrub with leaf margins not belled outward, leaf margins straight; flower stalks branched (inflorescence paniculate)

18a On dominant shrub, four to six individual (very small) flowers per head; found on deep, well-drained soils throughout the upper foothill and mountain areas where soil moisture is available most of the summer (MOUNTAIN BIG SAGEBRUSH/ BUNCHGRASS) . . . .

18b On dominant shrub, more than six individual (very small) flowers per head; often roots from branches in contact with soil (layering); found at high elevations (most commonly above 2 000 meters or 6,500 ft) (SUBALPINE BIG SAGEBRUSH/ BUNCHGRASS) . . . . (Treated briefly under mountain big sagebrush/ bunchgrass community description)

12b Dominant shrub not a sagebrush species

19a Dominant shrub spiney, bark is whitish; usually found on alkaline soil where water table is shallow—flood plains, playas, and terraces (BLACK GREASEWOOD/GRASS). . . . .

25b Fruits of dominant shrub mature from late August to October; widespread throughout the Great Basin of southeastern Oregon
(LOW SAGEBRUSH/BUNCHGRASS) . . . .

10b Communities without shrub cover, shrub cover sparse, or shrub cover sparse with introduced grass species (grass or forb communities not in key; see "SUCCESSIONAL VEGETATION," page 55)

26a Communities reseeded with introduced grasses and with or without introduced forbs, or communities appearing as bunchgrass types below 2 440 meters (8,000 ft) with or without a sparse shrub cover; mostly sagebrush communities with the shrub component eliminated or reduced by fire, chemicals, or mechanical means

27a Rehabilitated with introduced species; old seedings may have big sagebrush or rabbitbrush, and native grasses and forbs mixed at various densities with crested wheatgrass; seedings sometimes include introduced forbs
(CRESTED WHEATGRASS SEEDINGS—not discussed in text)

27b Rehabilitated without introduced species (shrub cover removed by fire, chemical, or mechanical means); residual native species used for natural reseeding of grass stand; often dominated by bearded bluebunch wheatgrass, with a mix of other species present
(SUCCESSIONAL VEGETATION) . . . .

26b Communities not reseeded

28a Sod-forming grasslands

29a Occurring in permanently wet situations along streams, ponds, or lake
(PERMANENTLY WET MEADOWS) . . . .

29b Occurring in places that are seasonally wet a significant part of the year; near streams or near other moist areas
(SEASONALLY WET MEADOWS) . . . .

28b Not sod-forming grasslands; bunchgrass communities in the subalpine zone above 2 440 meters (8,000 ft)
(SUBALPINE BUNCHGRASS) . . . .

Riparian Zone Communities

Riparian zones are identified by the presence of vegetation that requires free or unbound water or conditions that are more moist than normal (Thomas et al. 1979b). Riparian plant communities within this zone are complex and highly variable in structure, number of species, species composition, productivity, and size. This variability is due, in part, to the interaction of water quality, hydraulics, hydroperiod, topography, soil, geology, elevation, animal use, and alterations by people (Odum 1971, 1979; Thomas et al. 1979b). They are disproportionately important among Great Basin plant communities, yet there is probably less known about them than any other major zone under management.

Because of the complexity of the riparian zone and a lack of information on riparian vegetation in the Great Basin of southeastern Oregon, this section is limited to a general discussion. The riparian zone in relation to management is discussed by Thomas et al. (1979b).

1—RIPARIAN

Riparian communities vary structurally from a low grass and grasslike layer to a tree layer reaching above 25 meters (80 ft) and include many combinations of grasses, forbs, shrubs, and trees in between. Density of vegetation varies markedly. Because most woody vegetation is deciduous, however, hiding and thermal cover is effective primarily during the growing season.

Concentrated and valuable forage resources characterize this community. Intensive grazing may alter vegetation, causing not only a loss of forage but a different community structure and reduced productivity for the site. Soil losses through erosion of streambanks and lowering of water tables through channelization may permanently reduce plant productivity or change the vegetation. For example, a streambed lowered by erosion can cause a lower water table in the adjacent meadow and convert the meadow to a shrub community.

Management decisions must be made on a case by case basis because of the high variability between communities in the zone. Many critical site factors that influence productivity change from one riparian community to another.

Quaking Aspen Communities

Quaking aspen communities are scattered through mountainous areas of the Great Basin, most commonly at elevations from 1 550 to 2 150 meters (5,000 to 7,000 ft). These communities are usually found on wet sites but occasionally occur in combination with mountain big sagebrush.

2—QUAKING ASPEN/GRASS (fig. 9)

Vegetation

Crown cover of quaking aspen in the quaking aspen/grass community varies from 25 to 75 percent. Some stands have a two-tiered tree canopy—a mature and a reproduction layer. Mature stands reach a mean height of 21 meters (70 ft) with a mean stem diameter

Figure 9.—Quaking aspen/grass community along an intermittent streambed. Note the lack of reproduction and close cropping of grass and forbs by livestock and mule deer.

(breast high) of 36 centimeters (14 inches) and a maximum diameter of 56 centimeters (22 inches). Basal area (area of tree trunks covering the ground surface) of one large mature stand was 28 square meters per hectare (120 ft^2 per acre).[5] When present, the shrub layer is sparse and consists of occasional plants of mountain big sagebrush, green rabbitbrush, or mountain snowberry averaging 40 centimeters (16 inches) in height.

Grass and forb species, plant composition, and plant density vary among stands, partially because of varying amounts of moisture and severity of livestock use. Common grasses include blue wildrye, wheatgrass, needlegrass, hairgrass, or bottlebrush squirreltail[6] (see footnote 5). Total crown cover of the grass-forb layer may vary from less than 5 to over 30 percent. Height of the grass layer averages about 40 centimeters (16 inches).

Stinging nettle, a forb, often dominates disturbed stands. Other common forbs include peavine, aster, dandelion, sorrel, cinquefoil, and bedstraw (see footnotes 5 and 6). False hellebore and thistle are occasionally found. Dominant forb species average 1 meter (3.28 ft) tall. Some stands, however, lack tall forbs, such as stinging nettle, sorrel, false hellebore, and thistle. Height of forbs in such stands averages 30 centimeters (12 inches).

Site

Elevation of this community ranges between 1 830 and 2 300 meters (6,000 and 7,500 ft) in southeastern Oregon. It may occur near the top of mountains or on the middle, lower, toe, and bottom slopes; it often occurs around springs, seeps, lakes, ponds, or along streams on slopes from 0 to 30 percent. Some stands are extensive, occurring adjacent to and parallel with streams in unbroken bands up to 150 meters (500 ft) wide and several hundred meters long. Other stands are small patches of less than 1 hectare (2.5 acres) in size.

[5] J. Edward Dealy, unpublished data on file at Range and Wildlife Habitat Laboratory, La Grande, Oregon.

[6] Personal communication from A. H. Winward, Oregon State University, Corvallis.

Soil

Soils are moderately deep to deep, gravelly silt loams and loams. Cobble and stone volume in the soil varies, and coarse fragments on the surface are scarce. These soils are well drained, runoff is medium, and erosion hazard is moderate.

Discussion

Most stands have been intensively grazed by livestock for nearly 100 years. Since these sites are highly productive and found near water, wild and domestic ungulates concentrate on them. Reproduction of aspen on streamsides is damaged by grazing, except in areas where access by livestock has been restricted.

Beavers inhabit this community where there is sufficient running water. Damage to aspen reproduction by livestock and wild ungulates and to older trees by beavers has eliminated some stands, thereby eliminating beaver habitat. In one area, for example, there was one active beaver pond, one being built in an aspen stand too small to support the beaver, and approximately 15 abandoned ponds where aspen stands have been eliminated. It did not appear that these destroyed stands would become reestablished (see footnote 5).

Aspen stands provide valuable thermal and hiding cover for many vertebrate species, and nesting sites for birds, including cavity nesters.

3—QUAKING ASPEN/MOUNTAIN BIG SAGEBRUSH (fig. 10)

Vegetation

A single species tree stand of quaking aspen is typical of this community. It usually occurs as an open stand with less than 50-percent crown cover. Height ranges from 6 to 12 meters (20 to 40 ft), and trees on these sites often appear stunted and broad crowned with heavy lateral branches (see footnote 5). Occasionally, all mature trees in this type are either dying or dead. Some stands have a dead (snag) overstory above live reproduction, but in other

Figure 10.—Quaking aspen/mountain big sagebrush community illustrating the common branched tree form. Note the hole in the trunk used by cavity nesters (Chris Maser photograph).

stands both layers are dead. The causes of such mortality are unknown. It does appear, however, that these sites are marginal, and fluctuation in underground moisture or winter snowpack may be important factors. Also, long-term concentrated use of these small areas for forage and shade by livestock and big game may have consistently destroyed reproduction and prevented replacement of the old, degenerating stand.

Crown cover of quaking aspen reproduction ranges from 25 to 75 percent, and all heights may be represented, from a few centimeters to mature height. It is common, however, to see the aspen reproduction, where present, dominated by a single age and height class.

Mountain big sagebrush is the dominant shrub, with crown cover ranging from 15 to 40 percent. Average height is approximately 1 meter (3.28 ft). Gray rabbitbrush is the next most abundant shrub and may have crown cover as high as 20 percent. Green rabbitbrush is a consistent but sparse component; it increases in density, however, as moisture availability increases in severely grazed communities (see footnote 5).

Common perennial grasses and grasslike plants in disturbed stands of this type, in descending order of amounts of crown cover, are needlegrass, bottlebrush squirreltail, wheatgrass, and sedge. Annual cheatgrass is also common. Total crown cover of these species is less than 10 percent. Mean heights of needlegrass and wheatgrass are 50 and 60 centimeters (20 and 24 inches), respectively. Bottlebrush squirreltail and cheatgrass both average 25 centimeters (10 inches) in height, whereas sedge averages 5 centimeters (2 inches) (see footnote 5).

Forbs are sparse. Thistle and aster appear as occasional plants, and common dandelion is a rare component. Their total crown cover is generally less than 1 percent (see footnote 5).

Site

The quaking aspen/mountain big sagebrush community occurs most commonly on what appear to be dry sites between 1 550 and 2 150 meters (5,000 and 7,000 ft). It is present both in the Owyhee Uplands and Basin and Range Provinces (Franklin and Dyrness 1973). Macrorelief is mountainous and microrelief smooth. Slope ranges from less than 5 to 25 percent, and the position on a slope may be upper, middle, or lower. Slope aspects are generally northerly—from north-northwest to east-northeast (see footnote 5).

Soil

Soils are moderately deep, gravelly loams to sandy loams overlying basalt or rhyolite. They are well drained, and erosion hazard is moderate. Cobble and stone volume in the soil ranges from 5 to 30 percent, and coarse fragments cover less than 5 percent of the soil surface (see footnote 5).

Discussion

This quaking aspen community indicates a high soil moisture level, possibly caused by the combination of an unusual underground source of water and an exceptionally heavy snowpack.

All observed sites occur near maximum elevations on aspects roughly 180° from prevailing winter storm winds. Snowpack is deep and persistent compared with surrounding sites.

Use by livestock is intense in this community because of its high production of forage and tree shade. These stands are small; relative to the overall livestock forage resource of the adjacent open range, they have little impact. They appear to be important, however, as islands that maintain habitat diversity for wildlife and, therefore, merit management.

Curlleaf Mountainmahogany Communities (figs. 11 and 12)

Curlleaf mountainmahogany has two recognized varieties in the intermountain west. Only *Cercocarpus ledifolius* var. *ledifolius* is commonly present in the Great Basin of southeastern Oregon, occurring within four broad community groups: tree-sagebrush-bunchgrass, tree-snowberry-grass, tree-bunchgrass, and tree-grass (Dealy 1971, 1975).

Figure 11.—Extensive stands of curlleaf mountainmahogany blanket the tops and slopes of high desert mountains. Communities with open stands and understories of mountain big sagebrush differ from those with dense-canopied stands and a grass understory. Vegetation changes depend on changes in aspect and elevation which produce changes in available moisture.

Figure 12.—Dense curlleaf mountainmahogany stand upslope from a vigorous mountain big sagebrush stand. These two high value habitats commonly occur adjacent to one another and, as a result, increase diversity for deer (in foreground) and other wildlife. Precipitation is above 50 centimeters (20 inches).

4—CURLLEAF MOUNTAINMAHOGANY/MOUNTAIN BIG SAGEBRUSH/BUNCHGRASS (fig. 13)

Vegetation

This community is characterized by a patchy distribution of curlleaf mountainmahogany with a crown cover ranging from 35 to 60 percent and averaging 50 percent. Tree density varies between 800 and 2,000 stems per hectare (300 and 800 per acre) and averages 1,250 per hectare (500 per acre) with an occasional interspersed western juniper. Occasionally, ponderosa pine may occur within the stands.

The shrubby understory usually consists of a mountain big sagebrush layer of less than 5-percent crown cover. Density and vigor of sagebrush increase noticeably in the spaces between trees. Gray rabbitbrush, green rabbitbrush, wax currant, and Wyeth eriogonum are less common in the shrub layer.

Figure 13.—Curlleaf mountainmahogany/ mountain big sagebrush/bunchgrass community in the Great Basin of southeastern Oregon. Mountain big sagebrush grows densely and with high vigor under open tree canopies.

Dominant grasses are Idaho fescue, cutting wheatgrass, and big bluegrass. Other common grasses or grasslike species are California brome, bottlebrush squirreltail, Lemmon needlegrass, and Ross sedge.

Between 20 and 30 forbs occur in the understory. Lambstongue groundsel, arrowleaf balsamroot, western hawkweed, lupine, violet, and annual agoseris are most common.

Site

The curlleaf mountainmahogany/mountain big sagebrush/bunchgrass community occurs mostly on southerly facing slopes, ranging from 0 to 40 percent at elevations of 1 600 to 1 950 meters (5,250 to 6,400 ft). Mean elevation is 1 750 meters (5,750 ft). Macrorelief is mountainous and microrelief smooth. Since local topography in some areas is abruptly broken by ridges and hillocks, directional aspects may change within short distances.

Stands of this community occur on the driest sites suited to curlleaf mountainmahogany in the high desert mountains. When situated as narrow stringers on rimrock sites, the stands characteristically contain fewer species and some atypical species because of ecotonal influences within the narrow strip of the type.

Soil

The soil is well drained and varies from gravelly loam to gravelly sandy loam in the A horizon, and from gravelly clay loam to fine sandy loam in the B or AC horizon. Soil depth varies from 23 to 85 centimeters (9 to 33 inches) and averages 55 centimeters (22 inches). Soil surface cover of coarse fragments ranges from 1 to 60 percent and averages 32 percent. Cobble and stone volume in the soil ranges from 25 to 90 percent and averages 68 percent. Parent material can be either residuum or colluvium. Underlying material is generally either basalt or rhyolite. The soil is often shallow in stringer sites adjacent to rimrock, and stoniness of these soils is generally pronounced (Dealy 1975).

Discussion

This community has had a long history of heavy use by livestock—sheep in the early days and cattle more recently. This has resulted in an increase of understory species, such as gray or green rabbitbrush, cheatgrass, bottlebrush squirreltail, Lemmon stipa, or thistle. Generally, stands occur in a mosaic with mountain big sagebrush where relatively dense clumps of curlleaf mountainmahogany are interspersed with openings dominated by sagebrush and bunchgrass.

Fire easily kills curlleaf mountainmahogany. In many instances, patterns of burning are indicated by old, large trees in rocky, fire-resistant sites adjacent to young (60-80 year) stands in less rocky sites more vulnerable to fire. The old trees appear to have been missed by fire and provided the seed to reestablish adjacent stands. Many curlleaf mountainmahogany stands appear to have increased in size since fire has been controlled (Dealy 1975). Such action has been an advantage to wildlife in general since these stands provide important hiding and thermal cover for deer and bighorn sheep, as well as nesting sites for birds and ground-dwelling mammals.

5—CURLLEAF MOUNTAINMAHOGANY/ MOUNTAIN SNOWBERRY/GRASS

Vegetation

Stands of the curlleaf mountainmahogany/ mountain snowberry/grass community are characterized by a tree crown cover, ranging from 50 to 85 percent and averaging 70 percent. Such stands may vary in size from a few hectares to extensive areas with only small interspaces that may be dominated by grasses or shrubs (often mountain big sagebrush). Tree density varies from 900 to 3,200 stems per hectare (365 to 1,300 per acre) and averages 1,770 per hectare (720 per acre). An occasional western juniper may occur and, rarely, quaking aspen on moister sites (Dealy 1975).

The shrub understory commonly is a mixture of mountain snowberry and mountain big sagebrush. Dominance may change from one to the other in different stands. Crown cover is generally less than 5 percent. Other shrubs commonly found are green rabbitbrush, gray rabbitbrush, chokecherry, and creeping Oregon grape. Saskatoon serviceberry is present on about 50 percent of the area sampled. Other less commonly occurring shrubs are bittercherry and desert rockspirea.

Dominant grasses and grasslike species are big bluegrass or Idaho fescue in stands lightly used by livestock. Ross sedge and Sandberg bluegrass are common in most stands of the complex. In stands heavily used by livestock, there is an increase in bottlebrush squirreltail, cheatgrass, and Sandberg bluegrass.

Dominant forb species vary among sites in this community. Common species on dry sites are balsamroot, lupine, prairiesmoke avens, and varileaf phacelia; on moist sites—gray hawksbeard, heartleaf arnica, meadowrue, lambstongue groundsel, and Holboell rockcress.

Site

The driest stands of this community occupy south to southwest slopes at elevations averaging 1 770 meters (5,800 ft). Slopes average 30 percent.

Other stands are found on northerly aspects, varying from east-northeast to northwest at elevations between 1 800 and 1 900 meters (5,900 and 6,232 ft). Slopes range from 25 to 35 percent. Macrorelief is mountainous; microrelief generally rough. Topography is steep and abrupt in some stands and moderate in others.

Soil

Soils range from shallow to moderately deep and from a loam texture to gravelly loam. Cobble and stone cover of the soil surface ranges from 5 to 48 percent, and cobble and stone volume in the soil ranges from 27 to 81 percent. Parent material is generally colluvium or a mixture of colluvium and residuum material. Some soils overlay basalt; others occur over rhyolite (Dealy 1975).

Discussion

Density, vigor, and size of shrubs appear to be either a function of available moisture or an interaction of available moisture and tree crown cover (reduction of light) on the drier sites. Under dense tree canopies, shrubs are small, structurally weak, and scattered. In more open stands, however, shrubs are larger, more vigorous, and more dense. Increased available moisture within sites favors an increase in grasses and forbs rather than shrubs.

Stands of the community are habitat for mule deer and bighorn sheep. Livestock have also used these areas since the 1860's.

Fire control has permitted development, maintenance, and expansion of tree stands within the curlleaf mountainmahogany/mountain snowberry/grass community (Dealy 1975).

6, 7—CURLLEAF MOUNTAINMAHOGANY/ IDAHO FESCUE (fig. 14) AND CURLLEAF MOUNTAINMAHOGANY/BEARDED BLUEBUNCH WHEATGRASS-IDAHO FESCUE (fig. 15)

Vegetation

Tree cover varies from an average 66 percent in stands on the moister sites to 36

Figure 14.—Curlleaf mountainmahogany/Idaho fescue community commonly occurs adjacent to the ponderosa pine zone on moist northerly sites.

Figure 15.—Curlleaf mountainmahogany/bearded bluebunch wheatgrass-Idaho fescue community commonly occurs below and adjacent to the lower edge of the ponderosa pine zone.

percent on drier sites. Curlleaf mountainmahogany is the dominant species, but ponderosa pine occurs as scattered trees where the community is adjacent to the pine zone. Western juniper occurs as a subordinate species in some stands. Density of curlleaf mountainmahogany ranges from 500 to 2,000 stems per hectare (200 to 800 per acre). Stands are either patchy in distribution or occur as narrow bands perpendicular to the slope below and adjacent to the ponderosa pine zone. They occasionally encircle scab flats as bands within a ponderosa pine forest.

The shrub layer consists of occasional big sagebrush plants and rare plants of wax currant, gray rabbitbrush, green rabbitbrush, or antelope bitterbrush.

Grasses and grasslike species on sites indicating highest soil moisture are Idaho fescue (a strong dominant), bearded bluebunch wheatgrass, bottlebrush squirreltail, prairie junegrass, Sandberg bluegrass, California brome, Ross sedge, and cheatgrass. On drier sites, understories are bearded bluebunch wheatgrass and Idaho fescue in a codominant relationship. Both Sandberg bluegrass and bottlebrush squirreltail are more abundant, and prairie junegrass and cheatgrass remain about the same as on moist sites.

Forbs are scarce in the understory. Western hawkweed and phlox are most common on moist sites, and arrowleaf balsamroot is most common on drier sites. Occasional forbs are yarrow and annual agoseris.

Site

The curlleaf mountainmahogany/Idaho fescue community is found on most aspects from 1 600- to 1 700-meter elevation (5,250 to 5,575 ft). Northerly slopes ranging from 5 to 15 percent contain a dominant understory of Idaho fescue, whereas on other aspects with slopes ranging from 25 to 60 percent, bearded bluebunch wheatgrass and Idaho fescue are codominant. Macrorelief is mountainous, and microrelief varies from smooth to rough.

Soil

Soils are generally moderately deep, well-drained loams. Cobble and stone volume in the A horizon ranges from 5 percent where Idaho fescue is dominant to 30 percent where bearded bluebunch wheatgrass is codominant with Idaho fescue. Cobble and stone volume in B horizons is about 65 percent. Soils are developed from colluvium or weathered basalt. Permeability is moderate, runoff is estimated as medium, and erosion hazard is moderate (Dealy 1975).

Discussion

Use by cattle is minor in these stands because dense (70-percent crown cover), short stands of curlleaf mountainmahogany form a natural physical barrier. The trees commonly retain dead lateral branches below the live canopy. In a dense stand, these brittle but tough branches make penetration by cattle difficult. Domestic sheep travel through these thickets, however, as evidenced by wool hanging from low branches (Dealy 1971).

Tree crown cover averages 35 percent on sites having a high percentage of bearded bluebunch wheatgrass. Cattle move readily within these stands to graze the understory.

Mule deer use all sites for cover and forage; these sites, however, are more important to deer for cover than for forage (Dealy 1971).

8—CURLLEAF MOUNTAINMAHOGANY/ PINEGRASS (fig. 16)

Vegetation

Curlleaf mountainmahogany/pinegrass stands contain only one other tree species—an occasional bittercherry. Crown cover ranges from 62 to 96 percent and averages 80 percent. Density ranges from 1,400 to 4,700 stems per hectare (570 to 1,900 per acre) and averages 2,000 stems per hectare (800 per acre).

Shrubs are sparse; Saskatoon serviceberry and creeping Oregon grape are almost always present. Occasional shrubs are green rabbitbrush, gray rabbitbrush, and Wyeth eriogonum.

Pinegrass dominates the grass layer in light to moderately grazed stands. Big bluegrass is abundant, and Ross sedge, bottlebrush squirreltail, and cutting wheatgrass are common. Either Idaho fescue or Lemmon needlegrass is codominant with pinegrass in stands that have been heavily grazed by livestock. Other common grass and grasslike species in these heavily used stands are bottlebrush squirreltail, big bluegrass, and Ross sedge.

Western hawkweed is the dominant forb on relatively undisturbed sites. On disturbed sites, Nuttall violet dominates, western

Figure 16.—The curlleaf mountainmahogany/pinegrass community has the highest potential for production of dry land species in the Great Basin of southeastern Oregon.

hawkweed is found consistently in low abundance, and thistle and common dandelion increase with disturbance. Common forbs on all sites are prairiesmoke avens, annual agoseris, and yarrow.

The Alaska habenaria (commonly called Alaska rein-orchid) grows in low abundance in stands showing no evidence of litter disturbance. This plant develops a fleshy tuber delicately attached just below the interface of litter and mineral soil. It appears in stands protected from livestock and wild ungulate trampling by a dense tree thicket but disappears from sites where the litter-soil interface is even slightly disturbed (Dealy 1975).

Site

The curlleaf mountainmahogany/pinegrass community has been identified in the Owyhee Uplands (Dealy 1975) at elevations ranging from 1 750 to 1 920 meters (5,750 to 6,300 ft). It consistently occupies slopes facing east-northeast to north. Slopes range from 10 to 40 percent and average 24 percent. Macrorelief is mountainous, microrelief smooth. These sites experience heavy snowpacks during most winters. Measurements over a period of years have established annual precipitation at 56 centimeters (22 inches) (Dealy 1975).

Soil

Soils are moderately deep (48 centimeters or 19 inches), varying from gravelly loams to gravelly sandy loams, overlying fractured rhyolitic bedrock. Parent material is residual. Cobble and stone cover of the soil surface ranges from 0 to 10 percent and averages 3 percent; cobble and stone volume in the soil profile ranges from 15 to 80 percent and averages 44 percent. Soils under this community are well drained and moderately permeable. Runoff is medium and erosion hazard moderate to high (Dealy 1975).

Discussion

Domestic sheep and cattle grazing in the Owyhee Uplands, where this community occurs, was moderate to heavy during the late 1800's and early 1900's (Griffiths 1902). Since 1934, cattle have been the primary domestic animals grazing in the area. Historically, bighorn sheep and mule deer inhabited the area. Bighorn sheep were eliminated, however, near the turn of the century and did not return until 1965, when the Oregon Department of Fish and Wildlife reestablished them in some mountainous areas. Mule deer have been present throughout recorded history.

The curlleaf mountainmahogany/pinegrass community exhibits what may be the highest potential for production of dry land species in the high desert mountains of the northern Great Basin. Stands of this community where the Alaska habenaria occurs appear to be closer to pristine conditions than any others. This community is particularly valuable to birds and small ground-dwelling vertebrates.

Western Juniper Communities

Western juniper is unique to the intermountain west. Its center of development is the large woodland of central Oregon. It also occurs throughout southeastern Oregon, southwestern Idaho, northwestern Nevada, and northeastern California in scattered, open stands, as single trees, and rarely in more dense, extensive stands (Dealy et al. 1978a, 1978b) (fig. 17).

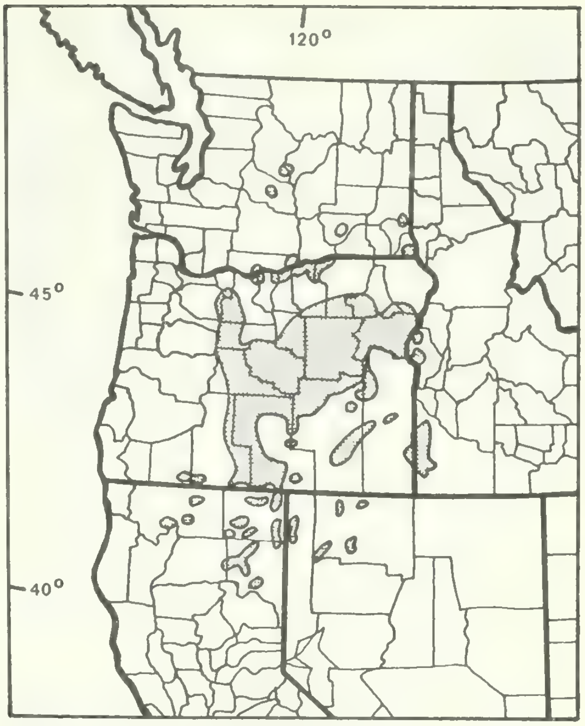

Figure 17.—Generalized distribution of western juniper (shaded portion) which occurs only in the Northwest (from Dealy et al. 1978a). Tree densities vary within and among the different localities.

9, 10—WESTERN JUNIPER/BIG SAGEBRUSH/BEARDED BLUEBUNCH WHEATGRASS (fig. 18) AND WESTERN JUNIPER/BIG SAGEBRUSH/IDAHO FESCUE

Vegetation

Western juniper in stands of these communities occurs primarily as a single overstory species with wide spacing. Some stands occur with a mature overstory, whereas others have recently developed with a young overstory on sites previously occupied by big sagebrush communities (fig. 19). Crown cover of western juniper is less than 35 percent in most stands.[7] Big sagebrush is the dominant shrub; gray rabbitbrush and green rabbitbrush are present in varying amounts. On moist sites, the shrub layer becomes less dominant and both western juniper and grass increase in importance. Occasionally, antelope bitterbrush and broom snakeweed are present (Driscoll 1964, Eckert 1957).

[7]Donavin A. Leckenby, Oregon Department of Fish and Wildlife, La Grande, Oregon, unpublished data.

Figure 18.—Western juniper/big sagebrush/bearded bluebunch wheatgrass community illustrating a mature stand of open juniper. Value as protective cover is high for ungulates, small mammals, birds, and other wildlife in the juniper communities.

Figure 19.—Before fire control and livestock grazing, this area supported a mountain big sagebrush/bunchgrass community. All western juniper trees here have become established since fire control and grazing (reduces grass fuel) reduced the frequency of fires.

Dominant grasses are bearded bluebunch wheatgrass or Idaho fescue. On some sites these grasses appear as codominants. Common grasses are Thurber needlegrass, bottlebrush squirreltail, Sandberg bluegrass, and cheatgrass. Burkhardt and Tisdale (1969) also found these grasses in the western juniper type in southwest Idaho. Occasionally plants of prairie junegrass and needleandthread occur in Idaho and Oregon stands (Burkhardt and Tisdale 1969, Roberts 1975; also see footnote 7).

Forbs in the juniper community include the following: locoweed, phlox, biscuitroot, fleabane, buckwheat, pussytoes, hawksbeard, annual agoseris, rockcress, arrowleaf balsamroot, and lambstongue groundsel.

Driscoll (1964) made an intensive study of western juniper communities, describing vegetation, site, and soils of nine associations and two variants in central Oregon. Three of these associations—western juniper/Idaho fescue, western juniper/bearded bluebunch wheatgrass, and western juniper/bearded bluebunch wheatgrass-Idaho fescue—have understories dominated by grass. The other six have understories with prominent big sagebrush layers, and the two variants have prominent antelope bitterbrush layers. Tables 3 and 4 list Driscoll's (1964) associations and present selected information on vegetation, site, and soil. Similar communities have been studied in south-central Oregon (Adams 1975, Roberts 1975). Intensive studies on western juniper communities are lacking for southeastern Oregon. Vegetation-site relationships, including plant and community structure, can be applied from Driscoll's (1964) work where similar conditions are found.

Site

The western juniper/big sagebrush/bearded bluebunch wheatgrass and western juniper/big sagebrush/Idaho fescue communities occupy level to hilly sites and ridges and northerly slopes in mountainous areas where moisture levels are higher than in the sagebrush steppe. Western juniper, as a type, occurs just below and abuts the curlleaf mountainmahogany zone. Precipitation ranges from approximately 25 to 38 centimeters (10 to 15 inches) per year. Macrorelief is level to mountainous, and microrelief can be rough in rimrock situations or smooth in deeper soils. Idaho fescue dominates the understory on sites with highest moisture, and bearded bluebunch wheatgrass is dominant on the driest sites. A more varied mixture of these grasses is found on sites of intermediate moisture.

Table 3—Number of macroplots and generalized characteristics of vegetation-soil units in the central Oregon juniper zone; reproduced from Driscoll (table 2, 1964)

Unit	Sample units	Aspect	Associated great soil group	Elevational range
	Number			Feet
Juniperus/Artemisia/Festuca	5	NW. to NE.	Chestnut	4,250-4,500
Juniperus/Artemisia/Festuca-Lupinus	4	N. to NE.	Regosol in Brown zone	4,400-4,550
Juniperus/Festuca	5	NW.	Brown	4,100-4,300
(*Purshia* variant)	(2)	(SE. to E.)		
Juniperus/Artemisia/Agropyron-Chaenactis	5	NW. to NE.	Regosol in Brown zone	3,900-4,400
Juniperus/Artemisia/Agropyron	5	Level	Brown	2,550-2,650
Juniperus/Agropyron	6	E. to NE.	Brown	4,150-4,450
(*Purshia* variant)	(2)	(SE.)		
Juniperus/Artemisia-Purshia	5	N. to NE.	Regosol in Brown zone	4,100-4,400
Juniperus/Agropyron-Festuca	5	E	Regosol in Brown zone	4,250-4,750
Juniperus/Artemisia/Agropyron-Astragalus	6	S. to SW.	Brown	4,000-4,400

Table 4—Average values of selected surface and subsoil characteristics attendant to nine associations in the central Oregon juniper zone; reproduced from Driscoll (table 3, 1964)

Association	Basal area perennial herbs	Bare soil surface	Available SMS[1] capacity, 2- to 14-inch zone	Organic matter, A horizon	Total nitrogen, A horizon	Horizon texture[2] A	Horizon texture[2] B or AC
	Percent	Percent	Inches water	Percent	Percent		
Juniperus/Artemisia/Festuca-Lupinus	7.4	22.1	1.41	4.78	0.21	l	c
Juniperus/Artemisia/Festuca-Lupinus	6.5	30.9	1.98	1.74	.10	sl	sl
Juniperus/Festuca	4.4	33.3	1.81	3.91	.17	l	sil, c
(*Purshia* variant)		(46.8)	(2.14)	(2.33)	(.10)	(l)	(c)
Juniperus/Artemisia/Agropyron-Chaenactis	5.2	52.3	.87	1.59	.08	sl	sl
Juniperus/Artemisia/Agropyron	6.6	41.3	2.31	1.50	.08	l	c, cl
Juniperus/Agropyron	3.2	51.1	1.34	2.12	.10	scl	c, cl
(*Purshia* variant)						(l)	
Juniperus/Artemisia-Purshia	3.1	55.0	1.54	1.05	.06	sl	sl
Juniperus/Agropyron-Festuca	4.1	54.7	.97	1.32	.07	sl	sl
Juniperus/Artemisia/Agropyron-Astragalus	3.5	45.7	1.21	1.63	.06	l	c

[1] SMS, soil moisture storage.

[2] The AC horizon is immediately below the A horizon in Regosols. B horizon textures were taken for the finest part of that horizon. Textural classes: cl, clay loam; l, loam; scl, sandy clay loam; sil, silt loam; c, clay; and sl, sandy loam.

Soil

Soils are highly variable in western juniper communities. Relatively young stands (100 years old or younger) have been reported on deep sandy loam soils in areas supporting the big sagebrush type before advent of fire control (Burkhardt and Tisdale 1969, 1976). Old-growth stands (more than 100 years) have been found on rocky rims having shallow soils. Eckert (1957), working in southeastern Oregon, found soils supporting western juniper to be in the Brown and Chestnut great soil groups that were derived primarily from residuum or colluvium of basalt and rhyolite origin. Some, however, developed on alluvial fans. Soil profiles were similar in many respects to those described by Dealy et al. (1978a, 1978b) and Driscoll (1964).

Discussion

Some authors have described western juniper as an "invader" in certain big sagebrush communities (Anderson 1956; Burkhardt and Tisdale 1969, 1976). Western juniper appears to be a strongly dominant native species but historically has been kept in a subordinate role on some sites because of natural fires (Dealy et al. 1978a, 1978b). Since fire control has been in effect and since severe livestock grazing began in the late 1800's, resulting in reduced grass-forb fuel for carrying fires, western juniper has increased its range and density in some areas

(fig. 19). Whether the increase of western juniper communities is an "invasion" or an "expansion" is important semantically because "invasion" has a negative connotation. It is more important that managers objectively recognize values of western juniper communities and retain them, if desired; this is consistent with the strategy of preserved diversity (Bella and Overton 1972).

The western juniper community is important for livestock production because of available shade, wildlife habitat (Leckenby 1977, 1978b; Maser and Gashwiler 1978), recreational activities, and erosion protection, to name a few values. A provisional list of 83 species of birds and 23 species of mammals that use western juniper communities was developed by Maser and Gashwiler (1978). The importance of thermal qualities of western juniper communities for mule deer has been documented by Leckenby (1977). Old-growth stands of western juniper provide a special habitat for cavity dwellers, such as the bushy-tailed woodrat (fig. 20).

Figure 20.—Nests of bushy-tailed woodrats in a hollow western juniper stem illustrate one of the many values of old growth for wildlife habitat (Chris Maser photograph).

Sagebrush Communities

Woody sagebrushes dominate the aspect (physiognomy) of the high desert shrub-steppe plant communities. These shrubs are distributed from Canada to Mexico and from the Pacific Northwest States to the Great Plains (Beetle 1960).

Aromatic gray sagebrushes appear as at least 13 distinctive taxa in Oregon. Among other characteristics, habitat, height, branching form, leaf shape, chromosome number, chromatographic response, and fluorescence in ultraviolet light help to identify the various important taxa (Beetle 1960; Hanks et al. 1971, 1973; Stevens and McArthur 1974; Winward 1980; Winward and Tisdale 1977). The above characteristics except chromosome number and chromatographic response, can be used in the field for identification of taxon. Heights of sagebrushes vary between extremes of the tall basin big sagebrush and the small bud sagebrush. Height of other species and subspecies declines between those extremes in about the following order: (1) subalpine big sagebrush, (2) mountain big sagebrush, (3) Wyoming big sagebrush, (4) mountain silver sagebrush, (5) Bolander silver sagebrush, (6) threetip sagebrush, (7) stiff sagebrush, (8) early low sagebrush, (9) low sagebrush, and (10) black sagebrush (see footnote 6, p. 18). Branching appears feathery and upright in basin big sagebrush and silver sagebrushes, tabular and compact in mountain big sagebrush, and globelike or flattened in black sagebrush (fig. 21). Leaves are predominantly wedge shaped, with three lobes (occasionally five or more) at the wide tip; silver sagebrush leaves are tapered to one tip, like lance points. Alcohol or water extracts of the leaves and other parts fluoresce characteristic shades of creamish-blue or brownish-red (table 5) in long-wave ultraviolet light (Stevens and McArthur 1974, Winward 1980, Winward and Tisdale 1977).

The various sagebrushes readily cross (genetic plasticity), as evidenced by similarities among their morphological characteristics (Beetle 1960).

At least four, and probably more, sagebrush taxa reach the same growth stages

Figure 21.—Three major growth forms of sagebrushes: A, feathery and upright; B, tabular and compact; and C, globular or flattened.

Table 5—Characteristic color shades of alcohol extracts of persistent leaves of 12 sagebrushes during exposure to long-wave ultraviolet light (after Winward 1980)

Sagebrush taxa	Shade of fluorescence: Creamish-blue	Shade of fluorescence: Brownish-red
Basin big sagebrush		X
Wyoming big sagebrush		X
Stiff sagebrush		X
Black sagebrush		X
Mountain big sagebrush	X	
Subalpine big sagebrush	X	
Threetip sagebrush	X	
Bolander silver sagebrush	X	
Mountain silver sagebrush	X	
Low sagebrush	X	
Cleftleaf sagebrush	X	
Early low sagebrush	X	

(phenology) at different times. For example, mountain big sagebrush initiates growth 2 weeks later and ripens seed 2 weeks earlier than basin or Wyoming big sagebrush; subalpine big sagebrush initiates growth later and seed development earlier than any other taxon; differences between basin and Wyoming big sagebrushes are not consistent (Winward and Tisdale 1977).

Winward and Tisdale (1977) discussed several management reasons for identifying sagebrushes to subspecies. Briefly, the various taxa of sagebrush provide indicators for (1) recognition of the plant environment or site (climate, soil, and other factors); (2) estimation of productive potential; (3) prediction of reaction to disturbance (changes in plant composition or stand structure); (4) determination of

range condition; (5) evaluation of forage preferences among stands; (6) applications of grazing systems; and (7) selection of treatment methods and schedules appropriate to accomplishment of management goals.

Sagebrushes can be separated conveniently into tall and short groups based on species, subspecies, and form. Each group requires different manipulations to meet management objectives for forage or cover. The tall sagebrush group is comprised of basin big sagebrush, mountain big sagebrush, Wyoming big sagebrush, subalpine big sagebrush, threetip sagebrush, mountain silver sagebrush, Bolander silver sagebrush, and other as yet undefined taxa. The short sagebrush group is comprised of low sagebrush, cleftleaf sagebrush, early low sagebrush, black sagebrush, stiff sagebrush, bud sagebrush, and other as yet undefined or unidentified taxa.

The recognition of species, subspecies, and forms of sagebrush supplies much information about a stand or a community—much that would take years to measure by other means; for example, weather stations. Variation in composition of plants among stands may identify differences in environments (Fosberg and Hironaka 1964); for example, stands of silver sagebrush, low sagebrush, and big sagebrush are usually separated by sharp ecotones because these species greatly differ in tolerance to soil moisture saturation. Silver sagebrush survives flooding and soil saturation longer than low sagebrush, and both silver and low sagebrush survive soil saturation better than big sagebrush. Tolerances for given environmental conditions vary even within species: Bolander silver sagebrush is more tolerant of alkalinity than is mountain silver sagebrush and occurs in closed basins; Wyoming big sagebrush is more tolerant of finer textured, alkaline soils than is basin big sagebrush and therefore dominates it on such sites.

The effect of climate on broad patterns of plant distribution is well accepted, and this effect is usually described and predicted by single factor relationships. For example, "Mean annual precipitation is never more than 363 mm in the *Artemisia* zone and never less than 408 mm in the *Pinus* forest" (Daubenmire 1956, p. 142); these moisture levels defined the sagebrush-forest ecotone in portions of Washington and Idaho. In another example, the threetip sagebrush-fescue zone is separated from a big sagebrush-wheatgrass zone and is associated with cooler temperatures from October through April and with higher precipitation and water balances in September, November, December, January, and March (Daubenmire 1970).

Microclimate is closely reflected by many plant species, and most of these are probably *not* dominants in the stand.

Grazing management has a marked influence on densities and crown cover of sagebrushes and cheatgrass.

Unusual and prolonged increases in soil moisture (i.e., water spreading as a management tool) drastically alter the relative dominance of western juniper, sagebrushes, and grasses. If flooding is of sufficient duration, pygmy woodlands and shrub steppes are converted to meadows or marshlike plant communities. Again, the characteristic species within the stand reflect the management. Not all interactions are obvious. There is still much to learn about a site from composition of plant species and how best to manage the site for specific goals (Daubenmire 1968, Pechanec et al. 1965).

Community composition reflects quality of forage, and community structure reflects quality of cover. Foraging animals preferentially browse some sagebrush species and subspecies more than others (Sheehy 1975; Smith 1950, 1952); cattle, domestic sheep, and pronghorns favor black sagebrush more than big sagebrush (Dayton 1931). In another study, mule deer and domestic sheep preferred mountain big sagebrush, Bolander silver sagebrush, and low sagebrush; the mule deer ate but did not prefer Wyoming and basin big sagebrush and showed the least preference for black sagebrush (Sheehy 1975). Chemical composition may influence the palatability of sagebrushes (Short et al. 1972). Sage grouse, horned larks, and pronghorns prefer low sagebrush stands

over big sagebrush stands of the high desert steppe. The taller big sagebrushes provide considerable shelter from the elements for cattle, domestic sheep, mule deer, and sage grouse and nesting sites for many animals. Few mammals and birds are small enough to effectively use the short sagebrush species for cover—thermal or hiding. Since many plant species of the shrub-steppe often comprise both forage and cover, composition of plant species as well as crown cover of stands are measures of site dominance and forage production. Height of vegetation cover and depth of crown, and layering (adventitious rooting from branches in contact with the soil) are attributes that directly create thermal and hiding cover.

Useful information is thus available from identification of the community; its identification is accomplished by means of characteristic plant species. This information can be applied in evaluation, selection, and application of program alternatives for management of that stand (Daubenmire 1968, Küchler 1957).

Sagebrush/bunchgrass communities are broadly distributed as a shrub-steppe type from Canada south through 11 Western States into Mexico (Beetle 1960, Garrison et al. 1977). Extensive areas of the type are found in Washington (5.9 million ha or 14.7 million acres), Oregon (10.9 million ha or 26.9 million acres), Idaho (15.0 million ha or 37.1 million acres), Nevada (13.7 million ha or 33.9 million acres), and California (7.3 million ha or 18.1 million acres) (Beetle 1960).

Stands vary from austere expanses dominated by single species to multihued mosaics rich in species.

Sagebrushes dominate arid, cold desert plains beginning at 30-meter (100-ft) elevation, but similar stands also mingle with moist, subalpine parklands up to 3 050 meters (10,000 ft) in elevation. The stands are distributed down drainages, within basins, up slopes, across plateaus, and along ridge crests.

Associated soils usually fall within either the Brown or Chestnut Great Soil Groups. Some sagebrush stands also occur on Chernozem or Sierozem soils (Fosberg and Hironaka 1964, Tisdale et al. 1969). Species distributions are generally correlated with soil depth and seasonal wetness. Franklin and Dyrness (1973) compiled information published by several authors and compared soils of four major sagebrush species: big sagebrush on deeper soils, low sagebrush on shallow stony soils, stiff sagebrush on very shallow stony soils (lithosols), and silver sagebrush in moister habitats.

Sagebrush communities of the Great Basin are valuable range habitats that help protect as well as produce multiple resources. Sagebrushes comprise a protective cover that minimizes wind and water erosion on many sites. Grazing of livestock is the primary measured economic use of the Great Basin sagebrush zone. Free-ranging big game and other wildlife provide many secondary benefits to society as well as an unmeasured but real economic flow within the region. Because of these values, results from manipulating sagebrush vegetation are important to the short-term and the long-range economic goals of Western States. Every management strategy in manipulating cover and forage qualities of the sagebrush range involves trade-offs in benefits to livestock and wildlife.

11—BASIN BIG SAGEBRUSH/ BUNCHGRASS (fig. 22)

Beetle (1960) described the range of basin big sagebrush in Oregon as extending from the southern end of the Blue Mountains, northeastern Oregon, throughout the central and southeastern portions of the State. Although he also recorded the basin form for every county east of the Cascade Range, Winward (1980) considered its range more restricted than that of other big sagebrush forms. The land area occupied by basin big sagebrush constitutes a minor portion of the sagebrush complex in Oregon; much of its former range is now cultivated land. Over recent history, the distribution has changed little, but various uses have considerably altered the density of stands (Winward and Tisdale 1977).

This tallest of big sagebrush forms is usually upright with erect spreading branches and a definite trunk (fig. 21); occasionally it may be either dwarf or treelike (Beetle 1960,

Figure 22.—A basin big sagebrush/bunchgrass stand illustrating the typical structure of this sagebrush subspecies and an understory that has been intensively grazed for a long time, resulting in reduced density of bunchgrass and an increase of annuals.

Winward and Tisdale 1977). The flower stalks are scattered throughout the irregular top. The persistent leaves are long and relatively narrow, shallow lobed, straight margined, and widest at the lobe tips. Alcohol extracts of the leaves fluoresce brownish-red in long-wave ultraviolet light (Winward 1980).

Vegetation

Diversity of species in some stands creates a rich composition, whereas other stands appear to be almost monotypes. Associated plants that are common enough to be used in naming big sagebrush communities and that also occur with basin big sagebrush are: Sandberg bluegrass, needleandthread, Idaho fescue, bearded bluebunch wheatgrass, giant wildrye, and Thurber needlegrass (Daubenmire 1970, Tisdale et al. 1965, Winward 1980). Franklin and Dyrness (1973, p. 235) compiled information from several workers and demonstrated the variety of plant species associated with big sagebrushes as well as the wide distribution of plants that identify the named communities (table 6). Detailed species lists for big sagebrush/bunchgrass communities where the big sagebrush form is unspecified are available in Concannon (1978), Culver (1964), Dealy (1971), Dean (1960), Eckert (1957, 1958), Hansen (1956), Segura-Bustamante (1970), Urness (1966), and Volland (1976).

Structure varies considerably among big sagebrush stands, and that variability influences their cover and forage qualities. Shrub height, crown cover, and plant density are commonly reported measures of structure of big sagebrush stands (table 7). Other important measures of structure seldom reported are the number and height of layers (vegetation strata) as well as hiding cover quality and crown depth. Many references contain structural measures, but most of these are concerned with big sagebrush in general—not a specific form, such as basin big sagebrush (table 7).

Site

In Oregon, basin big sagebrush is found primarily along valley bottoms and in lower foothill regions between 30 and 2 140 meters (100 and 7,000 ft) in elevation. This subspecies is also common to many sites with dry, shallow soils, southerly to westerly aspects, and at talus perimeters (Beetle 1960, Tisdale et al. 1965, Winward 1980). Basin big sagebrush is also found in valley bottoms and lower foothills from 700 to 2 140 meters (2,500 to 7,000 ft) in Idaho (Winward and Tisdale 1977).

Soil

Soil descriptions for many big sagebrush stands are readily available, but none were found that specified the subspecies of big sagebrush that was present. Winward and Tisdale (1977), however, describe basin big sagebrush in Idaho as "growing in deep, well-drained soils." Our observations indicate the tallest stands of basin big sagebrush (to over 2.4 m or 8 ft in height) grow in deep, well-drained soils alongside rivers and streams in southeastern Oregon. Big sagebrush/bunchgrass communities are common on shallow, moderate, and deep soils. Textures include silty clay loams through fine sandy loam and loamy sands to well-drained pumice sands (Culver 1964, Daubenmire 1970, Dealy 1971, Fosberg and Hironaka 1964, Hall 1973, Tisdale et al. 1965, Urness 1966, Volland 1976). The soil profiles generally show well-developed

Table 6—Characteristic species for *Artemisia* associations[1]

Association	Species group	High Lava Plains	Owyhee Upland	Southern Blue Mountains
Artemisia tridentata/ Agropyron spicatum	Shrubs	*Artemisia tridentata*	*Artemisia tridentata*	
	Grasses	*Agropyron spicatum*	*Agropyron spicatum*	
		Poa sandbergii	*Poa sandbergii*	
	Herbs	*Phlox diffusa*	*Lupinus sericeus*	
		Aster scopulorum	*Lomatium triternatum*	
		Aster canescens	*Lomatium macrocarpum*	
		Chaenactis douglasii	*Zigadenus paniculatus*	
		Collinsia parviflora	*Microseris troximoides*	
		Phlox gracilis	*Astragalus filipes*	
		Lappula redowskii	*Astragalus lentiginosus*	
		Gayophytum ramosissimum		
Artemisia tridentata/ Festuca idahoensis	Shrubs	*Artemisia tridentata*	*Artemisia tridentata*	
		Chrysothamnus viscidiflorus	*Chrysothamnus viscidiflorus*	
		Symphoricarpos rotundifolius		
		Ribes cereum		
		Juniperus occidentalis		
	Grasses	*Festuca idahoensis*	*Festuca idahoensis*	
		Agropyron spicatum	*Agropyron spicatum*	
		Poa sandbergii	*Poa sandbergii*	
		Koeleria cristata	*Sitanion hystrix*	
			Bromus tectorum	
			Elymus cinereus	
	Herbs	*Phlox diffusa*	*Balsamorhiza sagittata*	
		Antennaria corymbosa		
		Calochortus nitidus		
Artemisia tridentata/ Elymus cinereus	Shrubs		*Artemisia tridentata*	
	Grasses	*(mentioned but not described)*	*Elymus cinereus*	
			Poa sandbergii	
			Agropyron spicatum	
			Bromus tectorum	
	Herbs		*Penstemon speciosus*	
			Penstemon cusickii	
			Thlaspi arvense	
			Eriogonum umbellatum	
Artemisia arbuscula/ Agropyron spicatum	Shrubs	*Artemisia arbuscula*	*Artemisia arbuscula*	*Artemisia arbuscula*
		Eriogonum sphaerocephalum		*Purshia tridentata*
		Juniperus occidentalis		
	Grasses	*Agropyron spicatum*	*Agropyron spicatum*	*Agropyron spicatum*
		Poa sandbergii	*Poa sandbergii*	*Poa sandbergii*
		Festuca idahoensis	*Sitanion hystrix*	*Sitanion hystrix*
			Bromus tectorum	
	Herbs	*Phlox diffusa*	*Penstemon aridus*	*Trifolium macrocephalum*
		Erigeron linearis	*Lagophylla ramosissima*	
		Collinsia parviflora		
Artemisia arbuscula/ Festuca idahoensis	Shrubs	*Artemisia arbuscula*	*Artemisia arbuscula*	*Artemisia arbuscula*
		Juniperus occidentalis		
	Grasses	*Festuca idahoensis*	*Festuca idahoensis*	*Festuca idahoensis*
		Agropyron spicatum	*Agropyron spicatum*	*Agropyron spicatum*
		Poa sandbergii	*Poa sandbergii*	*Poa sandbergii*
	Herbs	*Phlox diffusa*	*Arabis holboellii*	*Phlox douglasii*
		Phlox hoodii	*Phlox diffusa*	*Balsamorhiza serrata*
		Phlox longifolia	*Erigeron linearis*	
		Microseris troximoides	*Astragalus miser*	
		Antennaria dimorpha	*Balsamorhiza hookeri*	
		Astragalus stenophyllus	*Agoseris heterophylla*	
		Lupinus saxosus	*Achillea millefolium*	
		Trifolium gymnocarpon	*Haplopappus stenophyllus*	
		Trifolium macrocephalum		
Artemisia rigida/ Poa sandbergii	Shrubs		*Artemisia rigida*	*Artemisia rigida*
	Grasses		*Poa sandbergii*	*Poa sandbergii*
			Bromus tectorum	*Sitanion hystrix*
			Festuca microstachys	
			Agropyron spicatum	
			Sitanion hystrix	
	Herbs		*Mimulus nanus*	*Phlox douglasii*
			Zigadenus paniculatus	

[1]Adapted from Franklin and Dyrness (1973, p. 235).

Table 7—Structural measurements reported for tall sagebrush stands

Taxon	Shrub height		Crown cover[1]	Density			Reference
				Plants	Area		
	Meters	Feet	Percent	Number	Square meters	Square feet	
Big sagebrush	0.4-2.0	1.2-6.6	—	—	—	—	Hitchcock et al. (1955)
	1.1	3.5	13	3-7	9.29	100	Tisdale et al. (1965)
	1.0-2.0	3.3-6.6	13-75	33	1076.00	100	Daubenmire (1970)
	.7	2.2	20-27	—	—	—	Culver (1964)
	.5-.6	1.7-1.9	7-12	11-15	18.58	200	Eckert (1957)
	.3-.7	1-2	7-27	—	—	—	Segura-Bustamante (1970)
	.4-.5	1.2-1.7	16-29	103-147	74.00	800	Urness (1966)
	.2-1.0	.6-3.3	9.8-16.6	.3-4.7	10.76	1	Kornet (1978)
	—	—	15-16	—	—	—	Volland (1976)
	—	—	4-15	—	—	—	Hall (1973)
Basin big sagebrush	.3-2.4	1-8	—	—	—	—	Brunner (1972)
	1.0-5.0	3.3-16.0	—	—	—	—	Beetle (1960)
	—	—	13.2	.057	.09	1	Sheehy (1975)
	1.2-2.4	3.9-7.9	—	—	—	—	Winward and Tisdale (1977)
Mountain big sagebrush	—	—	12	.088	.09	1	Sheehy (1975)
	.3-1.2	1.0-4.0	—	—	—	—	Brunner (1972)
	1.0	3.3	—	—	—	—	Beetle (1960)
Wyoming big sagebrush	.3-.9	1.0-3.0	—	—	—	—	Brunner (1972)
	—	—	8-23	—	—	—	Winward (1980)
	—	—	9.7	.078	.09	1	Sheehy (1975)
	.4-1.0	1.5-3.3	—	—	—	—	Winward and Tisdale (1977)
Threetip sagebrush	.5	1.7	10	14	9.29	100	Tisdale et al. (1965)
	1.0-2.0	3.3-6.6	—	—	—	—	Beetle (1960)
	.2-.6	.6-2.0	—	—	—	—	Hitchcock et al. (1955)
Silver sagebrush	1.5	4.9	—	—	—	—	Beetle (1960)
	.5-1.2	1.6-3.9	—	—	—	—	Peck (1961)
Bolander silver sagebrush	.3-0.6	1.0-3.0	—	—	—	—	Beetle (1960)
	—	—	27.8	.33	.09	1	Sheehy (1975)
Mountain silver sagebrush	1.0	3.3	—	—	—	—	Beetle (1960)

[1]Same as crown canopy, canopy closure, or crown density—the proportion of ground surface covered by shrub crowns as vertically projected, like a shadow.

horizons and often include a very fine-textured B horizon. Brown and Chestnut soils are most commonly associated with big sagebrush communities, but some stands have been found on other soils.

Discussion

The forage value of big sagebrush has been related to the quantity and quality of other browse species within the same or adjacent stands (Dietz and Yeager 1959; Short et al. 1972; Smith 1950, 1952). Use by wildlife varies among taxa of big sagebrush. For example, mule deer and domestic sheep preferred other subspecies to basin big sagebrush (Sheehy 1975, Winward 1980); basin big sagebrush was never grazed in Nevada (Brunner 1972).

Recognition of basin big sagebrush stands can aid the range manager in planning for maintenance or enhancement of cover and forage. Crown cover may increase dramatically because of crown enlargement after disturbance, and in such communities there is a greater potential for herbaceous production, native as well as introduced, than in some other big sagebrush communities (Winward 1980).

Burning of various big sagebrush/bunchgrass stands produces different responses among plant communities; different responses among basin big sagebrush communities should also be expected. Perennial grass cover is increased by burning of big sagebrush/bearded bluebunch wheatgrass stands, but fescue plants are damaged by fire (Daubenmire 1970, Concannon 1978). Fires eliminate big sagebrush and initiate plant successions during which perennial grass dominates the sites for long periods.

The influence of grazing in big sagebrush/bunchgrass stands may vary relative to the dominant form of big sagebrush. Daubenmire (1970) suggested that a big sagebrush/Sandberg bluegrass community did not result from overgrazing or burning of big sagebrush/bearded bluebunch wheatgrass stands. In Oregon, the quantity of Sandberg bluegrass increases as Idaho fescue declines, and this relationship is suggested as a measure of range condition (Tueller 1962). Sandberg bluegrass, along with bottlebrush squirreltail and longleaf phlox, increases as bearded bluebunch wheatgrass declines in burned stands of the big sagebrush/bearded bluebunch wheatgrass community (Concannon 1978). Tisdale et al. (1969) found that big sagebrush/Thurber needlegrass stands changed to big sagebrush/Sandberg bluegrass stands during heavy grazing.

Soils associated with big sagebrush communities influence the use of stands by burrowing mammals, the rooting depth of plants, the patterns of soil moisture through the seasons, and the responses of plants after disturbance. Stone-free soils of big sagebrush/fescue stands were favorable to voles, ground squirrels, and badgers (Daubenmire 1970). Rooting depths were greater or effective moisture was better in big sagebrush/giant wildrye stands compared with adjacent stands of other communities (Culver 1964). Cooler and moister sites were indicated by big sagebrush/fescue stands, but soil moisture was depleted earlier in the needlegrass phase of the big sagebrush/bearded bluebunch wheatgrass community (Eckert 1957). On pumice soils, manipulation of big sagebrush and other disturbances increased undesirable species, such as rabbitbrush, horsebrush, goldenweed, and bottlebrush squirreltail; burning produced grasslands that were slowly reinvaded by big sagebrush (Volland 1976).

Thorough identification of a plant community depends on the identification of its species—an important step in determining its potential for management toward various goals. This is often difficult to accomplish in one visit to a stand because of differences in timing of plant development among species. Dean (1960) presented an account of peak flowering times for species within big sagebrush types that illustrates this point.

12, 13—MOUNTAIN BIG SAGEBRUSH/BUNCHGRASS (fig. 23) AND SUBALPINE BIG SAGEBRUSH/BUNCHGRASS

The mountain big sagebrush subspecies is common in uplands from Oregon to the Rocky Mountains (Beetle 1960, Winward and Tisdale 1977). At higher elevations, mountain big sagebrush is replaced by subalpine big sagebrush, and an unnamed variant of mountain big sagebrush extends from the lower edge of the western juniper zone into the steppe communities in northeastern and central Oregon (Winward 1980). Mountain big sagebrush is found in all Oregon counties east of the Cascade Range, from below Anthony

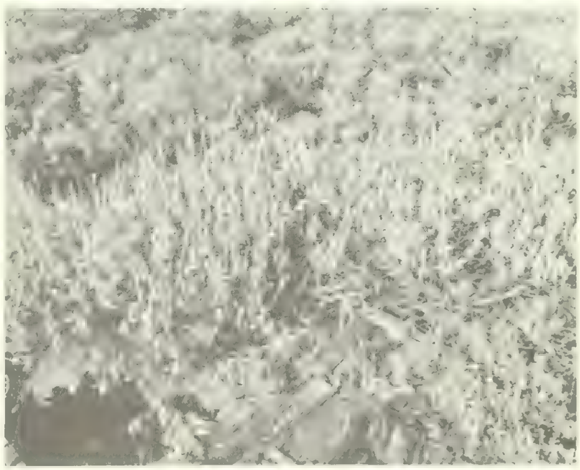

Figure 23.—Mountain big sagebrush/bunchgrass communities are species rich, have high forage production, and provide dense cover for many wildlife species.

Lakes in Baker County southwest to the Siskiyou Mountains in Josephine County (Beetle 1960, Winward 1980).

Mountain and subalpine subspecies of big sagebrush are moderately tall, flat-topped shrubs (fig. 21B); the flower stalks come from only the upper part of the branches and extend above the foliage (Beetle 1960, Winward and Tisdale 1977). The persistent leaves are wider relative to their length compared with basin big sagebrush, and they are broadest below the leaf lobes (Winward and Tisdale 1977). Alcohol extracts of the leaves of both the mountain and subalpine taxa fluoresce creamish-blue under long-wave ultraviolet light (Winward 1980).

Vegetation

Mountain big sagebrush/bunchgrass stands have a rich diversity of species; 40 plant associates are common (Winward 1980; also see footnote 7, p. 25). Some of the usual associates are the same as those found with other big sagebrush taxa (table 6). Bearded bluebunch wheatgrass, Idaho fescue, needleandthread, giant wildrye, bottlebrush squirreltail, and Sandberg bluegrass are usual dominants in the grass-forb layer. Prairie junegrass and Kentucky bluegrass are more usual with the subalpine form than with mountain big sagebrush. Rabbitbrushes are usually present, and their densities are greater in disturbed stands. California brome, slender wheatgrass, oniongrass, and sedges are common associates of subalpine big sagebrush (Winward 1980).

Mountain big sagebrush and the subalpine form have structurally dense stands (table 7); they have the potential for attaining greater crown cover than the other sagebrush species, subspecies, or form. Crown cover increases after disturbance and as range condition deteriorates (Winward 1980, Winward and Tisdale 1977).

Site

Many upper foothill and mountain sites from 1 070 to 3 050 meters (3,500 to 10,000 ft) in elevation are occupied by mountain big sagebrush (Beetle 1960, Winward 1980, Winward and Tisdale 1977). Schumaker and Hanson (1977) found the mountain form of big sagebrush on sites where annual precipitation varied from 0.5 meter (20 inches) to 1.1 meter (43 inches), slope varied from 6 to 33 percent, and aspects included east through northeast to north. Where both occur in high elevation areas, mountain big sagebrush is found on drier sites, subalpine big sagebrush on moister sites (Winward 1980).

Soil

Mountain big sagebrush occurs on deep, well-drained soils where moisture is available throughout most of the summer (Winward and Tisdale 1977). Schumaker and Hanson (1977) found this subspecies on mixed coarse and fine loamy soils from rhyolite and basalt as well as granite.

Discussion

The greater preference of ruminants for mountain big sagebrush forage may be related to phenological development, nutrient content, or essential oils. Mule deer have shown equal preference for mountain big sagebrush and its unnamed variant,[8] both being more preferred than basin or subalpine big sagebrush.[9] Sheehy (1975) found that mule deer and domestic sheep preferred Wyoming big sagebrush over mountain and basin big sagebrush. Brunner (1972) found that mountain big sagebrush was seldom grazed in Nevada. Growth of mountain big sagebrush is initiated later than that of basin and Wyoming big sagebrushes by about 2 weeks, but seed ripening of the mountain subspecies precedes that of the other two subspecies by about 2 weeks (Winward and Tisdale 1977). Cattle and domestic sheep grazed sagebrush principally in spring and fall according to Garrison et al. (1977), but Pechanec et al. (1965) found that sheep also depended on sagebrush for winter browse. Mountain big sagebrush shows the least variation in chemical content and also has the most persistent leaves among sagebrush taxa (Beetle 1960). The chemical value of different

[8]Personal communication from A. H. Winward, Oregon State University, Corvallis.

[9]Personal communication from D. P. Sheehy, Oregon Department of Fish and Wildlife, Burns.

sagebrushes compares favorably with other forages, although pure diets of sagebrush appear inadequate for maintenance of animals (Beetle 1960, Cook 1972, Dietz and Yeager 1959, Dietz et al. 1962). Consumption of sagebrush foliage may be limited by antimicrobial substances, such as essential oils, but inhibitory effects on the rumen microflora demonstrated in the laboratory (Nagy and Tengerdy 1968) are not likely to be attained in nature because of insufficient rates of release in the acid environment of the rumen (Short et al. 1972). Perhaps the varying consumption of sagebrush forms by grazers, however, is related to differences in consumption and content of essential oils among the sagebrushes (Sheehy 1975).

The dense structure of mountain and subalpine big sagebrush stands and their capacity for increases in plant density and crown cover after disturbance make these communities valuable cover habitats for wildlife. Managers should plan periodic control of parts of some stands to develop openings for mule deer, thus producing more diversity and greater edge length. In fawning and fawn-rearing areas dominated by mountain big sagebrush or subalpine big sagebrush, some dense stands of either form may be best left alone (Winward 1980). The mountain subspecies is readily controlled by flooding (Beetle 1960), as are other forms of big sagebrush (see footnote 8).

Seeding managed stands of mountain big sagebrush with crested or intermediate wheatgrass and seeding stands of subalpine big sagebrush with intermediate wheatgrass, California brome, or smooth brome are usually successful. Seeding, however, is infrequently required because the understory is usually in good condition (Winward 1980). Large populations of gophers in some dense stands of subalpine big sagebrush sufficiently disturb the soil to increase the annual forb component.

14—WYOMING BIG SAGEBRUSH/ BUNCHGRASS (fig. 24)

Wyoming big sagebrush is the most common sagebrush throughout the high desert in Oregon (Winward 1980). It is a low growing

Figure 24.—Wyoming big sagebrush/bunchgrass communities occur on relatively dry sites and are the most common of the sagebrush-dominated communities in the Great Basin of southeastern Oregon (Chris Maser photograph).

shrub, 0.4 to 1 meter (1.5 to 3.3 ft) tall, with an irregular and rounded top (fig. 21A) and with the flower stalks scattered throughout the crown—like small shrubs of basin big sagebrush. The main stem is not trunklike, however, but is comprised of two or three twisted portions at ground level. The persistent leaves are relatively short and wide, more deeply lobed than in other big sagebrush taxa, and their margins curve outward from the base to form bell-shaped blades. Alcohol extracts from the leaves fluoresce shades of brownish-red in long-wave ultraviolet light (Winward 1980, Winward and Tisdale 1977).

Vegetation

Many plant species commonly occurring with Wyoming big sagebrush are also found with other taxa, such as basin or mountain big sagebrush. Major associated species include: bearded bluebunch wheatgrass, needleandthread, Thurber needlegrass, bottlebrush squirreltail, Sandberg bluegrass, and cheatgrass. Idaho fescue occurs occasionally with Wyoming big sagebrush (Schumaker and Hanson 1977, Winward 1980). Many stands have a sparse grass-forb layer because of heavy use by livestock and wildlife; some stands and the understory have been altered by natural,

periodic burning (Winward 1980). These disturbances and loss of understory are associated with increased density of sagebrush or other shrubs. There are few perennial forbs, antelope bitterbrush is not a natural component, and cryptogams may fill much of the bare areas in undisturbed stands. The lateral rooting of this subspecies may compete more with herbaceous species than that of other big sagebrush taxa (Winward and Tisdale 1977). A correlation between crown cover or crown diameter and production has been determined for this subspecies (Rittenhouse and Sneva 1977). The stands are not structurally dense (table 7), yet they may totally occupy the site.

Site

Wyoming big sagebrush/bunchgrass is most common at elevations of less than 1 830 meters (6,000 ft) and on more xeric mountain sites than other big sagebrush communities (Winward 1980). Schumaker and Hanson (1977) described stands on northeast aspects of 8-percent slope in an area with 33 centimeters (13 inches) of annual precipitation. The subspecies is common on slopes of major drainages in hot and dry areas from 700 to 1 980 meters (2,500 to 6,500 ft) in Idaho (Winward and Tisdale 1977). In Nevada, this subspecies is found within the terrace sagebrush complex (Brunner 1972).

Soil

Relatively shallow to moderately deep soils are present under stands of Wyoming big sagebrush/bunchgrass; often the soil is slightly calcareous in the surface layer (Winward 1980, Winward and Tisdale 1977). Fine, loamy soils from basalt were associated with the community in Idaho (Schumaker and Hanson 1977); the community is also found on "redrock surfaces" over deep soils in Nevada (Brunner 1972).

Discussion

Wyoming big sagebrush was of low to intermediate palatability for mule deer and domestic sheep in Oregon compared with six other sagebrush taxa (Sheehy 1975, Winward 1980). Conversely, this subspecies was as palatable as antelope bitterbrush and often severely grazed in parts of Nevada (Brunner 1972). Sparse grass-forb layers are common in Wyoming big sagebrush/bunchgrass stands, and they offer little forage from associated plant species.

Dense, low cover for small animals is offered by some stands of Wyoming big sagebrush. Often, however, the shrubs are too small or scattered to provide much protection, especially not for large mammals and birds. Disturbances of the grass-forb layer causes only moderate increases in density of this subspecies.

15—THREETIP SAGEBRUSH/BUNCHGRASS (fig. 25)

Threetip sagebrush is distributed in Washington, Idaho, and Oregon (Beetle 1960, Daubenmire 1970). Within Oregon, the species occurs in Baker and northern Harney counties and occasionally in Malheur County (Beetle 1960, Winward 1980; also see footnote 8, p. 36).

Figure 25.—Threetip sagebrush/bunchgrass stand in a usual topographic location. The elevation of this stand, 865 meters (2,837 ft), in northern Malheur County, Oregon, is lower than reported in the literature (see footnote 5, p. 18).

Threetip sagebrush is an erect shrub (fig. 21A) that freely and profusely branches to form a moderately large crown, 0.4-0.8 meter (1.3-2.6 ft) in diameter (Beetle 1960). This species does not normally root from its branches (layering) because of its upright form;

it readily does so when the branches touch the soil, and it sprouts readily from burned crowns (Beetle 1960). Dwarf threetip sagebrush is a low subspecies in some stands, is rarely taller than 0.2 meter (0.7 ft), has a crown from 0.3 to 0.4 meter (1.0 to 1.3 ft) wide, and readily layers from its naturally decumbent branches (Beetle 1960). This subspecies is usually found adjacent to mountain big sagebrush but not mingled with it; dwarf threetip sagebrush occupies shallow soils along ridges rather than the deeper soils at the base of foothills (Beetle 1960).

The leaves of threetip sagebrush are relatively long, 3 centimeters (1.2 inches), and deeply three cleft into linear lobes which may also be divided (Beetle 1960). Alcohol extracts of the persistent leaves fluoresce creamish-blue under long-wave ultraviolet light (Winward 1980).

Vegetation

Many plant species found with big sagebrushes in general, occur with threetip sagebrush in its fescue and wheatgrass communities (Daubenmire 1970, Tisdale et al. 1965, Winward 1980). Plant species composition for the threetip sagebrush/fescue and threetip sagebrush/wheatgrass communities were similar except for the occurrence of fescue. Extensive species included the following: rabbitbrush, big sagebrush, antelope bitterbrush, squaw apple, Sandberg bluegrass, bearded bluebunch wheatgrass, prairie junegrass, needleandthread, Thurber needlegrass, Kentucky bluegrass, threadleaf sedge, arrowleaf balsamroot, dwarf hesperochiron, longleaf phlox, nineleaf biscuitroot, and tapertip hawksbeard.

Canopy cover measurements are high where plants are dense (table 7), since individual crowns are of large diameter, 0.4 to 0.8 meter (1.3 to 2.6 ft), and freely branched (fig. 21A). Threetip sagebrush may form stands sufficiently dense to crowd out herbaceous species (Winward 1980).

Site

Threetip sagebrush/fescue stands occur on moist and cool sites, such as north and east slopes and in depressions, whereas threetip sagebrush/bearded bluebunch wheatgrass stands are found on dry, warm sites where exposure to sun and wind is too severe for fescue; for example, on east slopes curving to the north there are abrupt ecotones between the communities (Daubenmire 1970, Tisdale et al. 1965). In Oregon, this species is reported at elevations of 1 160 meters (3,800 ft) or higher by Winward (1980). Dealy (see footnote 5, p. 18) reports a low elevation of 865 meters (2,837 ft) for this species in northern Malheur County, Oregon. Beetle (1960) reported that threetip sagebrush occurred between 914 and 1 830 meters (3,000 and 6,000 ft).

Soil

Threetip sagebrush is the only resprouting sagebrush species associated with loam to sandy-loam soils in Oregon (Winward 1980). Daubenmire (1970) found stands of the threetip sagebrush/bunchgrass community on Brown, Chestnut, Chernozem, Planosol, and Prairie soils in Washington and Idaho. Threetip sagebrush communities were associated with silty clay loams containing a B horizon at 0.2-0.3 meter (0.7-0.8 ft) and a lime zone below 0.9 meter (2.9 ft) in Idaho (Tisdale et al. 1965). In general, threetip sagebrush communities are associated with deep, well-drained soils (Beetle 1960).

Discussion

Apparently the intensity of browsing of threetip sagebrush varies by subspecies and areas. Winward (1980) considered that grazing by native and domestic animals contributed to the density of present threetip sagebrush/bunchgrass stands. Brunner (1972) observed that threetip sagebrush was never grazed, but he reported that dwarf threetip sagebrush was usually severely grazed.

The structure of threetip sagebrush/bunchgrass stands should provide considerable cover, but the shorter dwarf threetip sagebrush can protect only smaller animals. The resprouting ability and growth form can produce very dense brush fields that vigorously compete with herbaceous species (Winward 1980). Stable shrub densities cannot be maintained with proper grazing or even no use;

periodic thinnings are necessary to attain some management goals. Sandberg and Kentucky bluegrasses are common in threetip sagebrush/bunchgrass stands, and crested wheatgrass can be established on these sites (Winward 1980).

The stone-free mound soils associated with some threetip sagebrush communities provide a favorable substrate for burrowing rodents and badgers (Daubenmire 1970).

16, 17—BOLANDER SILVER SAGEBRUSH/ BUNCHGRASS (fig. 26) AND MOUNTAIN SILVER SAGEBRUSH/BUNCHGRASS (figs. 27 and 28)

Silver sagebrushes are found in seasonally moist areas from central and eastern Oregon eastward across the Rocky Mountains to Nebraska and the Dakotas. Two subspecies are associated with two distinct habitats, closed basins and streamside or pond-edge meadows, that are scattered throughout the Pacific Northwest and intermountain regions (Beetle 1960). The basin subspecies, Bolander silver sagebrush, is distributed within the desert areas of Oregon from Prineville throughout the southeastern third of the State; the streamside-meadow subspecies, mountain silver sagebrush, is most common in east-central and southeastern Oregon where there are seasonally high water tables adjacent to streams and meadows (Dealy 1971, Winward 1980).

These two silver sagebrush subspecies differ morphologically, chemically, and ecologically. Bolander subspecies is a low rounded shrub with erect or spreading dense branches, but mountain silver sagebrush can be taller and more erect (Beetle 1960). Branching of both subspecies creates an irregular crown (fig. 21A). Branches of both subspecies readily form roots when they touch the soil, and the plants resprout from the root crown. The leaves are tapered toward both ends, are usually not lobed, are very silky with white hairs, and smell pungent (like turpentine) when crushed (Beetle 1960). Alcohol extracts of leaves from either subspecies fluoresce creamish-blue shades under long-wave ultraviolet light (Winward 1980). The unlobed leaves and tolerance

Figure 26.—This stand of Bolander silver sagebrush/bunchgrass on an internally drained basin site illustrates the usual bare soil interspaces and sparse understory.

Figure 27.—Mountain silver sagebrush/ bunchgrass stand adjacent to a mountain meadow.

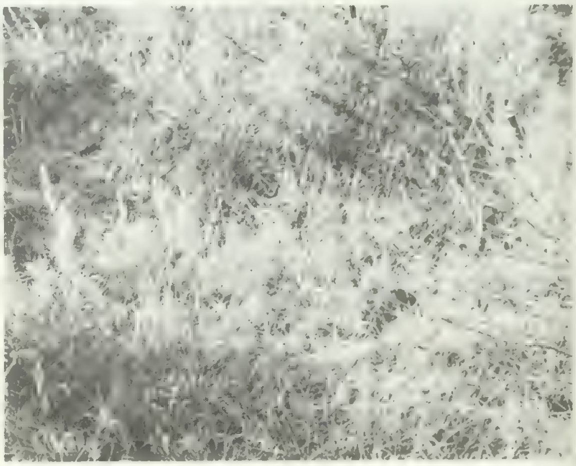

Figure 28.—This detailed view of a mountain silver sagebrush/bunchgrass stand illustrates the usually dense understory.

of soil saturation and seasonal flooding clearly set both silver sagebrushes apart from all other shrubby, tall sagebrushes. Leaves of the other tall species are cleft three or more times, and those shrubs are easily killed by even brief periods of flooding or soil saturation.

Vegetation

Moist sites dominated by silver sagebrushes support rich herbaceous understories in spring, but these understories are usually maintained through the grazing season only in mountain silver sagebrush stands. The sagebrushes are usually the only shrubs present, but muhly, spike rush, rushes, sedges, and a few forb species are associated (Dealy 1971, Winward 1980; also see footnote 7, p. 25). Other plants commonly observed in Bolander silver sagebrush stands include: Douglas sedge, Baltic rush, Newberry cinquefoil, bottlebrush squirreltail, showy downingia, combleaf, tiny mousetail, and cheatgrass (Leckenby and Toweill 1979, Sheehy 1975). Herbaceous species are more abundant in the floristically rich mountain silver sagebrush stands and include some species not present in Bolander silver sagebrush communities, such as: slender wheatgrass, California brome, Nevada bluegrass, sedges, timothy, and Kentucky bluegrass[10] (Winward 1980).

Structural attributes of free branching, layering, and crown sprouting can create considerable cover, but silver sagebrushes are seldom sufficiently tall (table 7) to provide cover for animals larger than swans, geese, rabbits, and coyotes.

Site

Subspecies of silver sagebrush are closely associated with sites that are seasonally very moist to saturated or even temporarily flooded (usually late winter and spring) (Beetle 1960, Cornelius and Talbot 1955, Dealy 1971, Winward 1980; also see footnote 7, p. 25). This single environmental condition eliminates most other plants common to shrub-steppe communities. The internally drained, alkaline basins dominated by Bolander silver sagebrush are frequently ponded to depths of 0.3-0.6 meter (1-2 ft) for at least a month each spring when the snowpack melts. There have been years—1965, for example—when flooding persisted even beyond the tolerance of silver sagebrushes and aerial portions of the shrubs died. The dead branches were replaced within 3 years by new or resprouted individuals, after the basins passed through a structural condition dominated by Newberry cinquefoil and annual forbs (see footnote 7, p. 25). Sites containing the mountain subspecies usually are saturated in spring and early summer, but normally they are covered only briefly with standing water. The exception is found in wet meadows that form ponds (Dealy 1971). Both subspecies occur at midelevation to high elevation: Bolander silver sagebrush, 1 000-1 800 meters (3,500-6,000 ft); mountain silver sagebrush, 1 680-2 240 meters (5,500-8,000 ft) (Beetle 1960, Winward 1980; also see footnote 8, p. 36).

Soil

Silver sagebrush communities are associated with deep soils of variable surface texture (sand to clay) (Beetle 1960, Cornelius and Talbot 1955). Within Oregon, however, these subspecies are dominant on deep clay and alkaline soils (Leckenby and Toweill 1979, Urness 1966, Winward 1980). Clay soils found with mountain silver sagebrush develop wide deep cracks as they dry over the summer, and the flaking surface layers readily slough into deep fissures (Cornelius and Talbot 1955; also see footnote 10).

Discussion

Use of silver sagebrush/bunchgrass stands varies among seasonal ranges. Bolander silver sagebrush foliage is highly preferred by mule deer and domestic sheep (Sheehy 1975; also see footnote 7, p. 25). These basin communities are occupied by mule deer more than expected from their availability on the Silver Lake-Fort Rock winter range (Leckenby 1978a, Urness 1966). On summer range in the same area, Dealy (1971) considered silver sagebrush/muhly stands of low value because they constituted a small area and thus provided limited forage compared with that in adjacent communities. Dealy (1971), however, found that

[10]Schallig, W. H. C., unpublished data on file at Oregon State University, Corvallis.

competition between livestock and deer appeared high for the limited herbaceous forage available. All silver sagebrush communities should be considered important foraging habitats for mule deer, pronghorns, and sage grouse.

Depth and density of vegetation may provide good cover in some mountain silver sagebrush stands, but cover is sparse in the severely grazed alkaline basins dominated by Bolander silver sagebrush. Pronghorns frequently use these "flats" as resting and bedding areas throughout the summer.

The heavy soils and seasonal ponding make forage improvement in most silver sagebrush sites risky at best; introduced species have rarely survived well (Cornelius and Talbot 1955, Leckenby and Toweill 1979, Winward 1980). These communities are best left untilled and unsprayed because of their wildlife value and because the native plants are difficult to replace with other forage species that do as well.

Waterholes are often developed in silver sagebrush basins. Frequently, ditches are dug across the basin floor to drain a shallow pond rapidly into a deep reservoir which maintains a reliable water source longer through the livestock grazing season. The improved drainage produces a shorter period of flooding; new, drier, plant habitats are created that favor big sagebrush and rabbitbrushes over silver sagebrush. In smaller basins, silver sagebrush stands are being slowly replaced by big sagebrush-rabbitbrush communities (Leckenby 1978a). Thus, some trade-offs among multiple resource goals are illustrated in the case of silver sagebrush basins altered for enhancement of water sources for livestock.

18—STIFF SAGEBRUSH/BUNCHGRASS (fig. 29)

Stiff sagebrush (also called scabland sagebrush) communities occur from the Cascade Range and Blue Mountains of Washington through central and southeast Oregon into Idaho (Daubenmire 1970). This short sagebrush species is found regularly at the northern end of the Great Basin within eastern

Figure 29.—The site on which this sparse stand of stiff sagebrush/bunchgrass occurs illustrates the severe conditions under which the species can grow in the Great Basin of southeastern Oregon.

Oregon. It is common in the following Oregon counties: Wasco, Wheeler, Crook, Gilliam, Jefferson, Umatilla, Union, Wallowa, and Harney (Beetle 1960). Winward (1980) found stiff sagebrush stands distributed primarily in northern and northeastern Oregon, but stiff sagebrush was also located from northern Harney County east through Malheur County into Idaho.

Stiff sagebrush is a winter deciduous, low, spreading, and dense shrub (fig. 21C) that consists of short, rigid, decumbent, and brittle branches (Hitchcock et al. 1955, Peck 1961, Winward 1980). Alcohol extracts of the narrow-based and tridentlike lobed leaves fluoresce brownish-red under long-wave ultraviolet light (Winward 1980).

Vegetation

Stiff sagebrush/bunchgrass plant communities are often floristically rich but may appear impoverished because of spacing between plants and sparse ground cover (Daubenmire 1970). Common associated plant species include several mosses (*Tortula, Bryum, Ceratodon, Grimmia*), woodlandstar, biscuitroot, spring draba, autumn willowweed, pink microsteris, dwarf monkeyflower, Sandberg bluegrass, cheatgrass, Pacific fescue, bearded bluebunch wheatgrass, and bottlebrush squirreltail (Culver 1964, Daubenmire

1970, Winward 1980). Hall (1973) found dwarf squirreltail, false agoseris, a biscuitroot, and bighead clover common to stiff sagebrush stands in the Blue Mountains. Other common associated species are listed in table 6.

Although many species provide diversity of forage, the small shrubs and open stands provide little cover for other than the smallest animals (table 8).

Site

Stiff sagebrush in the Great Basin of Oregon is found exclusively on various aspects of rocky scablands that have undulating or rolling relief. Stiff sagebrush/bunchgrass stands are found from 914 to 2 134 meters (3,000 to 7,000 ft) in elevation. They are usually on gentle slopes or benches of 0- to 20-percent slope and occasionally on steeper slopes of up to 40 percent (Beetle 1960, Culver 1964, Hall 1973, Winward 1980).

Soil

Stiff sagebrush communities are associated with very shallow to shallow 10- to 28-centimeter (4- to 11-inch), stony soils that have been developed from basalt and rhyolite (Culver 1964, Daubenmire 1970, Hall 1973, Winward 1980). Soil textures vary from loams to fine clay loams. The profiles usually become saturated with water in winter and spring and are regularly subjected to frost heaving or frost boils.

Discussion

Big game and livestock use stiff sagebrush as browse (Daubenmire 1970, Hall 1973, Winward 1980; also see footnote 7, p. 25). Many commonly associated species are valuable forage for grazing animals.

The low stature and dispersion of stiff sagebrush shrubs does not provide cover of any consequence for animals larger than

Table 8—Structural measurements of short sagebrushes

Sagebrush species	Shrub height		Crown cover[1]	Density			Reference
				Plants	Area		
	Meters	Feet	Percent	Number	Square meters	Square feet	
Stiff	0.2-0.4	0.6-1.3	—	—	—	—	Peck (1961)
	—	—	20	—	-	--	Culver (1964)
	—	—	10-34	—	—	—	Daubenmire (1970)
	—	—	5-20		—	—	Hall (1973)
Low	.1-.4	.3-1.3	13-16	55-56	18-58	200	Eckert (1957)
	—	—	26	—	—	—	Culver (1964)
	.1-.2	.4-.5	4-22	1.2-8.3	—	—	Kornet (1978)
	—		10.8	.18		—	Sheehy (1975)
	—	—	10	—	—	—	Volland (1976)
	.2-.3	.7-.9	6-20		—	—	Segura-Bustamante (1970)
	.2	.7	8-26	—	—	—	Dealy (1971)
Black	—	—	11.8	.28	—	—	Sheehy (1975)
	.1-.3	.3-1.0	—	—	—	—	Beetle (1960)
	.1-.4	.3-1.3	—	—	—	—	Hitchcock and Cronquist (1973)
	.3	1.0		—	—	—	Brunner (1972)
	.1-.3	.3-1.0	—	—	—	—	Dayton (1931)
Early low	.2	.8	1.5	25	9.29	100	Tisdale et al. (1965)
	.3	1.0	—	—	—	—	Beetle (1960)

[1]Same as crown canopy, canopy closure, or crown density—the proportion of ground surface covered by shrub crowns as vertically projected, like a shadow.

horned larks or ground squirrels. The lack of leaves (this is the only deciduous shrubby sagebrush in the area) in winter severely reduces the little cover this species offers on the scablands during periods of thermal stress. Even in winter, however, the shrubs do provide some protection from erosion by wind (Hall 1973).

Stressful environmental conditions for plant growth, such as waterlogging and consistent frost heaving of very shallow soils, make successful seedings of domestic grasses highly improbable (Hall 1973, Winward 1980). Removal or control of the stiff sagebrush cover would increase thermal stress for small animals, reduce the forage available for both large and small animals, and increase erosion by wind.

19, 20—LOW SAGEBRUSH/BUNCHGRASS (fig. 30) AND CLEFTLEAF SAGEBRUSH/BUNCHGRASS (figs. 31 and 32)

Low sagebrush/bunchgrass communities typically occur adjacent to or intermixed with big sagebrush communities but are distinctly separate stands of an edaphic (soil-related) climax vegetation associated with shallow, stony soils (Dealy 1971, Dealy and Geist 1978, Franklin and Dyrness 1973). Low sagebrush is common in most counties east of the Cascade Range in Oregon. Beetle (1960) listed the counties where low sagebrush occurs (Baker, Grant, Crook, Jefferson, Wheeler, Harney, Malheur, Lake, Klamath, and Jackson.

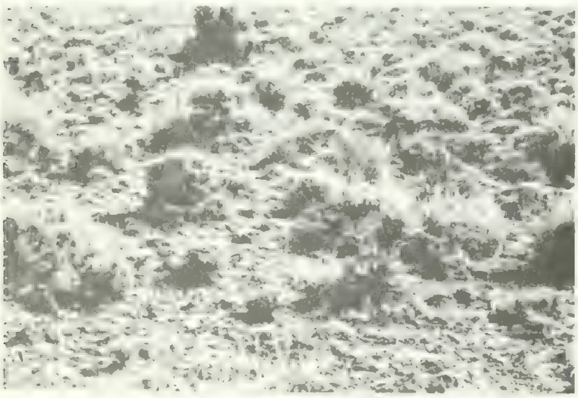

Figure 30.—Low sagebrush/bunchgrass communities are common on shallow, stony soils (photo, courtesy Oregon Department of Fish and Wildlife).

Figure 31.—This stand of cleftleaf sagebrush/bunchgrass occurs at 1 524 meters (5,000 ft) in east-central Malheur County, Oregon, adjacent to curlleaf mountainmahogany. This is a new location in Oregon for the subspecies (see footnote 5, p. 18).

Figure 32.—Closeup of a cleftleaf sagebrush/bunchgrass stand illustrating the habit (general appearance) of this subspecies of sagebrush and the gravelly, shallow soil of sites on which it grows in the Great Basin of southeastern Oregon.

Low sagebrush is a gray to green dwarf shrub formed of irregular, short, and stiff branches (fig. 21C). It produces a small crown between 0.4 and 0.8 meter (1.3 and 2.6 ft) wide (Beetle 1960, Brunner 1972). The species infrequently forms roots from branches touching the soil. Both the small, narrow, wedge-shaped, and deeply three-toothed leaves of low sagebrush, as well as the much thinner lobed leaves of the subspecies cleftleaf sagebrush, fluoresce

creamish-blue in alcohol solutions exposed to long-wave ultraviolet light (Winward 1980). A taller variant (as yet unnamed) associated with pumice soils requires more research (Winward 1980.)

Vegetation

Stands vary from small—2 hectares (5 acres)— to wide "flats"1.6 kilometers (1 mi) or more across. The usual associated plants create a rich diversity of species within these stands of vegetation. Common associates are: bearded bluebunch wheatgrass, Idaho fescue, Thurber needlegrass, Sandberg bluegrass, prairie junegrass, one-spike oatgrass, bottlebrush squirreltail, cheatgrass, western needlegrass, woolly eriophyllum, Bloomer fleabane, low pussytoes, yarrow, gay penstemon, Nevada biscuitroot, Holboell rockcress, starved milkvetch, obscure milkvetch, spreading phlox, longleaf phlox, Hooker balsamroot, annual agoseris, daggerpod, granite gilia, bighead clover, and nineleaf biscuitroot (Culver 1964; Dealy 1971; Dean 1960; Eckert 1957, 1958; Hall 1973; Segura-Bustamante 1970; Volland 1976; Winward 1980; also see footnote 7, p. 25).

As with other structurally short sagebrushes, low sagebrush shrubs are too small and too scattered to provide cover for large animals (table 8), but the dense crowns do shelter small animals, such as lizards, snakes, birds, and mice. The evergreen low sagebrush does, however, maintain its minimal cover qualities through winter better than does the deciduous stiff sagebrush.

Site

Low sagebrush/bunchgrass communities are regularly found on dry, relatively sterile, often alkaline sites (Beetle 1960). Although Beetle (1960) reported low sagebrush often occurring on alkaline sites, Brunner (1972), presenting data on the sagebrush genus in Nevada, and Dealy (1971), studying low sagebrush in Oregon, report low sagebrush only on acid to neutral sites. Occurrences are between 914- and 2 743-meter (3,000- and 9,000-ft) elevation. The stands are on most aspects, but commonly they are found on gentle slopes (2-15 percent) in rolling to undulating or flat uplands, top-of-rim edges, level and sloping plateaus, and crests and slopes of ridges (Culver 1964; Dealy 1971; Dean 1960; Eckert 1957, 1958; Hall 1973; Segura-Bustamante 1970; Volland 1976; Winward 1980).

Soil

Low sagebrush thrives on shallow, stony, fine-textured soils derived from basaltic, andesitic, or rhyolitic parent materials. These soils may have basic, neutral, or acidic reactions. They generally are less than 0.6 meter (2 ft) deep, may contain an impermeable (or at least restrictive) clay B horizon, become saturated with water in late winter and spring, and are extremely droughty in summer (Brunner 1972, Culver 1964, Dealy 1971, Dealy and Geist 1978, Eckert 1957, Fosberg and Hironaka 1964, Hall 1973, Segura-Bustamante 1970, Volland 1976, Winward 1980; also see footnote 7, p. 25). Lack of physical support during spring periods of soil saturation can result in damage from trampling (Hall 1973). Extremes of saturation, frost heaving, and drying in these soils make plant survival tenuous at best. Though the species are well adapted, even the low sagebrush and Sandberg bluegrass roots are pedestaled and broken during seasonal cycles of frost heaving and soil drying. Often, cracks in the underlying base rock, or interrupted restrictive layers in the solum produce dispersed soil microsites that are deeper and better drained than surrounding soil. This permits establishment and survival of a few scattered ponderosa pine, western juniper, curlleaf mountainmahogany, antelope bitterbrush, or other shrubs (Dealy and Geist 1978, Segura-Bustamante 1970).

Discussion

Low sagebrush stands are intensively used by wildlife and are particularly important to large ruminants, including livestock. Mule deer regularly and preferentially occupied these communities during mild weather in winter and spring (Leckenby 1978a). Use by pronghorn and sage grouse is also high, though less seasonal. Indigenous species of wildlife intensively graze the associated forbs and grasses. Browsing of low sagebrush by insects, mice, rabbits, hares, sage grouse, and ruminants is also extensive.

Forage species develop as much as 2 weeks earlier in low sagebrush stands than in the adjacent antelope bitterbrush, tall sagebrush, rabbitbrush, western juniper, curlleaf mountainmahogany, or ponderosa pine communities. Grazing animals follow the sequence of forage development which is induced by differences in site factors among these communities. Similar grazing patterns exist elsewhere and appear to be an expression of resource partitioning related to rates of plant growth which in turn are correlated with different plant habitats. In a shortgrass zone, deBoer (1974) found that herds of grazing wildlife preferred plant communities produced by a shallow soil overlying a restrictive hardpan (a soil environment similar to that of short sagebrush stands). Low total herbaceous production and low rates of growth on these sites apparently permitted earlier season grazing that was nonselective for plant species and that maintained growth of vegetative parts that were highly digestible. Two other vegetational zones, both characterized by more precipitation, deeper soils, and lack of a restrictive layer, produced higher rates of plant growth (soil environments similar to those of tall sagebrushes and other steppe communities). There, the grazing animals exhibited marked selectivity of forage species and grazed these stands much later and less intensively than those of the shortgrass zone.

Low sagebrush was one of the most preferred sagebrushes offered to mule deer and domestic sheep (Sheehy 1975). Some subspecies of low sagebrush are grazed more extensively than others by mule deer and other wildlife (Brunner 1972, Dealy 1971, Leckenby 1978a, Volland 1976, Winward 1980). In addition, the plant composition of many stands offers a rich diversity of seasonal forages.

Height, crown cover, and plant density of low sagebrush/bunchgrass stands provide little structure to create hiding or thermal cover for animals larger than ground squirrels, mice, and small birds; these communities are primarily habitats for production of forage. Total crown cover of all vegetation was less where low sagebrush/bunchgrass stands were compared with adjacent big sagebrush communities of similar composition (Segura-Bustamante 1970): western juniper/antelope bitterbrush-big sagebrush, 39-percent total cover; western juniper/antelope bitterbrush-low sagebrush, 38 percent; antelope bitterbrush-big sagebrush, 36 percent; antelope bitterbrush-low sagebrush, 34 percent; big sagebrush, 35 percent; and low sagebrush, 23 percent. Crown cover of western juniper, however, was similar among stands dominated by either sagebrush. Abundance of forbs increased steadily, whereas total crown cover decreased in those stands. Densities of bearded bluebunch wheatgrass, Thurber needlegrass, Sandberg bluegrass, and Idaho fescue were greater where these grasses occurred with low sagebrush compared with big sagebrush/bunchgrass stands (Segura-Bustamante 1970).

Management designed to harvest or improve production of forage from low sagebrush/bunchgrass stands should be planned after careful evaluation of the goals, trade-offs, and risks. These sites are fragile, generally will not produce much more forage after treatment, are not suitable for cultivation, and occur on soils that are too shallow for crested wheatgrass or other readily available introduced species (Dealy 1971, Hall 1973, Volland 1976, Winward 1980). Abundance of remnant forbs and grasses may improve with changes in grazing management (Dealy 1971, Winward 1980), but some stands in poor condition have apparently not changed even where they were completely protected for 30 years or more.

Identification of specific low sagebrush plant communities requires data from more than one season (Leckenby 1978a). Dean (1960) described plant species appearance (especially phenology of flowering) in spring, summer, and autumn. The marked differences in time of plant species appearance, recognition, or prominence in the physiognomy (outward feature) of a stand produce quite different impressions of low sagebrush communities. In spring when obscure milkvetch is prominently flowering, the foliage easily contrasts with the wet soils; in summer when the colorful ashy penstemon is in full bloom, the obscure milkvetch has all but disappeared.

21—BLACK SAGEBRUSH/BUNCHGRASS

Black sagebrush is more common in that portion of the Great Basin east of Oregon (Hitchcock et al. 1955), but Beetle (1960) reported it scattered in Oregon's Harney and Lake Counties. Winward (1980) found that the relatively few areas of this sagebrush occurred primarily in the southern portions of Malheur, Harney, and Lake Counties. West et al. (1978) observed black sagebrush in many stands throughout Nevada and in Utah.

The shrub is low to dwarf (fig. 21C); its branches are decumbent; the flower stalks are brown and persistent (Beetle 1960). Although some authors consider black sagebrush a variety of low sagebrush (Hitchcock and Cronquist 1973), there are important differences (Winward 1980). There may be subspecies of black sagebrush that are also important to recognize, for at least a glossy-green form appears to be grazed less than a gray-green form (Brunner 1972). Beetle (1960) also described these color phases. The broadly wedge-shaped (flabelliform), three- to five-lobed leaves produce alcohol solutions that fluoresce brownish-red during exposure to long-wave ultraviolet light (Winward 1980).

Vegetation

Plant species associated with black sagebrush communities are often the same as those found with stiff and low sagebrush communities. Species lists from black sagebrush/bunchgrass stands regularly include one or more of the following: bearded bluebunch wheatgrass, Indian ricegrass, bottlebrush squirreltail, and Sandberg bluegrass; occasionally, needleandthread may be present (Winward 1980).

Short stature and wide spacing of shrubs throughout the stands create sufficient cover for hiding or thermally protecting only the smallest animals (table 8).

Site

Vegetation stands of black sagebrush/bunchgrass occur between 1 200 and 2 740 meters (4,000 and 9,000 ft) on drier, shallow sites (Beetle 1960, Dayton 1931, Winward 1980). The species is common to level plains and slopes in foothills and mountains and is reported to occur with ponderosa pine, aspen, and woodland types—even into the spruce-fir zone (Dayton 1931).

Soil

The black sagebrush/bunchgrass community, like other short sagebrushes, is associated with shallow, stony soils (Beetle 1960). This species, however, has particular affinity for calcareous soils (Brunner 1972, Winward 1980). Either lime hardpans or a concentration of lime is present in most soils supporting this sagebrush species. Such a relationship contrasts with that of the neutral to acid volcanic soils common to low sagebrush stands (Brunner 1972, Dealy 1971).

Discussion

Six other sagebrush species were more palatable than was black sagebrush to mule deer and domestic sheep (Sheehy 1975). Pronghorns (Winward 1980), domestic sheep, and domestic goats (Dayton 1931) were reported to intensively graze black sagebrush. Use may depend on the variety, form, or subspecies present (Brunner 1972). Cultural treatment and seeding of forage or cover plants are not likely to improve composition and structural qualities of black sagebrush stands. Disturbance of these stands initiates long succession from Sandberg bluegrass dominance back to other bunchgrasses. Often, stands in poor condition have not recovered although they were protected from grazing (Winward 1980).

22—EARLY LOW SAGEBRUSH/BUNCHGRASS

Early low sagebrush has also been called alkali sagebrush (Beetle 1960, Tisdale et al. 1969) and early sagebrush (Winward 1980). This species is also found primarily east of Oregon, but limited local stands exist in Deschutes, Crook, Lake, and Harney Counties (Beetle 1960, Brunner 1972, Tisdale et al. 1965, Winward 1980). Eckert (1957) reported a large-headed form of low sagebrush that flowered

from mid-July until mid-August in northern Lake and Harney Counties; the phenology of the form he observed matches that of this uniquely early-flowering species of short sagebrush.

The form and stature of early low sagebrush and the sites it is common to in many ways resemble those of low sagebrush. It is a dwarf shrub (fig. 21C) with lax and spreading branches that frequently layer (Beetle 1960). These two short sagebrushes, early low and low, form adjacent pure stands; but they may also occur mixed together (Eckert 1957, Winward 1980). These species cannot be readily separated on the basis of leaf form or fluorescence. Alcohol extract solutions fluoresce creamish-blue from exposure to long-wave ultraviolet light (Winward 1980). Difference in phenology is the most suitable diagnostic characteristic to separate early low and low sagebrush (see footnote 8, p 36).

Vegetation

Plants associated with early low sagebrush are commonly found in stands of other short sagebrushes. Typical lists include pussytoes, wild buckwheat, phlox, violet, Idaho fescue, Thurber needlegrass, Sandberg bluegrass, and bottlebrush squirreltail (Tisdale et al. 1965).

Early low sagebrush stands offer little structural cover because of plant density (table 8). Stands rich in species may serve as valuable forage areas, but only small animals find much shelter in typical stands.

Site

Early low sagebrush stands are found at elevations from 1 830 to 2 440 meters (6,000 to 8,000 ft) on poorly drained, hot, and dry sites; the ecological situation is similar to sites dominated by low sagebrush (Beetle 1960, Winward 1980.)

Soil

Brunner (1972) found early low sagebrush in pure stands on shallow stony soils, but the species also occurred in mixed stands with other sagebrushes on deeper soils. The name "alkali sagebrush" came from plants found on fine textured and highly alkaline soils (Beetle 1960). In Idaho, Tisdale et al. (1965) associated this species with a silty clay loam subsoil at 0.1 meter (0.3 ft) and a strongly developed B horizon at 0.3-0.4 meter (1-2 ft).

Discussion

Early low sagebrush, except for its earlier flowering, may be best considered a form of low sagebrush (Winward 1980). Its preference as forage by mule deer has not been evaluated. This species was not grazed in Nevada and was seldom eaten by sage grouse (Brunner 1972). Management of early low sagebrush stands should enhance or preserve the diversity of native forage species and adjust the grazing season to accomplish that goal. Crested wheatgrass is not adapted to the sites because of the shallow, heavy, and seasonally saturated soils.

Other Communities Dominated by Shrubs

23—SQUAW APPLE/BUNCHGRASS (fig. 33)

Squaw apple is an intricately and rigidly branched, deciduous shrub that may attain heights of 2 meters (6.5 ft) (Hitchcock and Cronquist 1973). Subspecies or varieties have not been identified.

Figure 33.—Squaw apple/bunchgrass community illustrating the large, robust form of the species and other species that commonly occur with it, such as mountain big sagebrush and bearded bluebunch wheatgrass (Chris Maser photograph).

Vegetation

Although squaw apple is seldom the dominant (measured by canopy cover) shrub of broad expanses, it may occasionally assume dominance in some stands. Squaw apple constitutes the tallest shrub layer except where antelope bitterbrush is present. A variety of other shrub species comprise the shorter shrub layer. Squaw apple also occurs in eastern Oregon in association with scattered ponderosa pine and western juniper.

Squaw apple communities may have as many as four major strata, the tallest at a height of 1.5 meters (5 ft). Mountain big sagebrush may average 0.8 meter (2.5 ft) and is usually the dominant shrub of the middle shrub layer with green and gray rabbitbrush occasionally present. The subshrub granite gilia and the shrublike slenderbush eriogonum comprise a sparse, low shrub layer 0.5 meter (1.5 ft) tall. The herbaceous layer averages 0.2 meter (0.5 ft) tall and consists primarily of wild buckwheat, fleabane, rockcress, low pussytoes, Thurber needlegrass, bearded bluebunch wheatgrass, Sandberg bluegrass, and cheatgrass.

Communities are characterized by a shrub cover of approximately 10-15 percent.

Often two to five squaw apple bushes may be found growing close together so that their branches intertwine, giving the illusion of one huge shrub, 2.0-2.5 meters (6.5-8 ft) in diameter.

Threetip sagebrush, averaging 0.6 meter (2 ft) tall, occasionally dominates the intermediate shrub layer. Also included in this layer are a few scattered big sagebrush, gray rabbitbrush, and green rabbitbrush. Threetip sagebrush and the rabbitbrushes are rounded shrubs that branch from near the base. The basal leaves of wild buckwheat and low pussytoes may form small islandlike mats on the otherwise stony and bare surface.

Site

The range of squaw apple is restricted to high, moist hillsides in the northern portion of southeastern Oregon. The topography is generally characterized by rolling hills and prominent drainages.

Soil

Squaw apple commonly occurs on moderately deep, well-drained soils. Texture generally varies from loam to sandy loam. The percent of soil surface covered by cobbles and stones and cobble and stone volume in the soil profile are highly variable.

Squaw apple also occurs on very shallow, medium-textured soils derived from weakly consolidated, occasionally fractured tuff and diatomaceous deposits. Plant density is likely controlled, in part, by fracturing frequency of the soil parent material. Plant crowns act as a protective influence on these highly erodible soils.[11]

Discussion

Hayes and Garrison (1960) described squaw apple as fair browse for domestic sheep and cattle in spring and for deer in the winter. Beneath the canopy of squaw apple is a well-concealed haven for small animals. Stem density is high in the interior of squaw apple crowns, providing small birds excellent protection from predators.

24—BLACK GREASEWOOD/GRASS (fig. 34)

Black greasewood is a spiny, freely branched shrub that may grow nearly 2.5 meters (8 ft) high (Hitchcock and Cronquist 1973). The succulent leaves of this deciduous species give a luxuriant appearance to the plant (Shantz and Piemeisel 1940). The bright yellow green of communities dominated by black greasewood contrasts with the gray green of sagebrush communities during the summer. The species is not relished by livestock, but severe grazing may produce smaller plants with compact canopies. Black greasewood will resprout from the root crown after fire (Daubenmire 1970).

[11] J. Michael Geist, unpublished data on file at Range and Wildlife Habitat Laboratory, La Grande, Oregon

Figure 34.—The black greasewood/grass community is one of the tallest of the shrub types and provides excellent protective cover for nesting birds and small mammals and thermal cover for all species.

Vegetation

Generally, black greasewood communities have shrub and herbaceous layers, but community structure varies, depending on species composition or age class.

Some black greasewood areas contain few other shrubs, and in pure stands the plants are widely spaced with large interspaces of bare soil (Shantz and Piemeisel 1940). On some sites with almost pure stands, the shrub cover ranges from 10 to 20 percent and averages between 0.9 meter and 1.2 meters (3 and 4 ft) tall. The interspaces are mainly barren but are occasionally occupied by cheatgrass and bottlebrush squirreltail. Russianthistle is present but restricted to disturbed areas near roads.

Black greasewood comprises 90-95 percent of the shrubs in stands of the valley bottoms; the remainder consists of very large shadscale saltbush plants (reaching heights of 1 meter—3.28 ft), green rabbitbrush, and basin big sagebrush. Cheatgrass, which usually dominates the herbaceous layer, is confined beneath shrub canopies.

Patches of the strongly rhizomatous desert saltgrass occur in areas of greater moisture. Desert saltgrass swards occur in some dense black greasewood communities where the shrub cover may reach almost 30 percent. Black greasewood dominates the shrub layer, both in percent composition and height—1.3 meters (4.3 ft). Big sagebrush and green rabbitbrush also occur. In some communities, giant wildrye attains the greatest height of any species but is present only in small amounts; however, this grass may have been more prevalent before grazing. A layer of cheatgrass is common between and beneath the shrubs, and the amount of bare ground varies according to fluctuations in the density of this species.

Site

The black greasewood/grass community reaches its best development on lowlands in the Great Basin of southeastern Oregon, occurring primarily on saline-sodic flood plains, playas, and terraces. On middle slopes of about 10 percent, spiny hopsage, as well as giant wildrye and green rabbitbrush, is conspicuous in the black greasewood community. On the lower slopes, spiny hopsage and shadscale saltbush become prominent. The low growing bud sagebrush occurs sparingly, and cheatgrass dominates the herbaceous layer.

Soil

The black greasewood/grass community generally occurs on soils exhibiting high alkalinity and high water tables (Potter 1957); however, Shantz and Piemeisel (1940) reported alkali is not necessary for the presence of black greasewood, but a high moisture content of the soil is.

Discussion

The black greasewood/grass community provides thermal cover for all species of wildlife and excellent protective cover for nesting birds and small mammals. This excellent cover is primarily due to the tall growth form of black greasewood combined with its spines and coarse structure.

Rickard (1964) reported sagebrush was replaced by black greasewood in an area that had been excessively grazed. The attendant loss of a relatively nonsaline surface layer produced a saline-sodic environment where water was available only to the halophytic black greasewood. This indicates the limited options

available for management of stands that occur on marginal sites.

25—SHADSCALE SALTBUSH/ BUNCHGRASS (fig. 35)

Vegetation

Shadscale saltbush/bunchgrass is the dominant community on large expanses of the high desert in southeastern Oregon (see footnote 5, p. 18). Crown cover in most stands averages 15 percent and ranges from 10 to 35 percent. Heights average 37 centimeters (15 inches) and range from 30 to 45 centimeters (12 to 18 inches). Spiny hopsage is a common species, generally with a crown cover of less than 5 percent; height averages 62 centimeters (24 inches) and ranges from 50 to 70 centimeters (20 to 28 inches) between sites. Big sagebrush is a sparse component in most areas, with an average crown cover of less than 5 percent and an average height of 56 centimeters (22 inches), ranging from 50 to 70 centimeters (20 to 28 inches). Big sagebrush generally appears as small patches within the type, indicating a possible variation in soil. Bud sagebrush is common on most sites, with a crown cover averaging less than 5 percent but ranging up to 10 percent in some areas; average height is 15 centimeters (6 inches), ranging from 10 to 20 centimeters (4 to 8 inches). The only other shrubs commonly present are gray and green rabbitbrushes, normally with less than 1-percent crown cover. Heights of gray and green rabbitbrushes average 48 and 30 centimeters (19 and 12 inches), respectively.

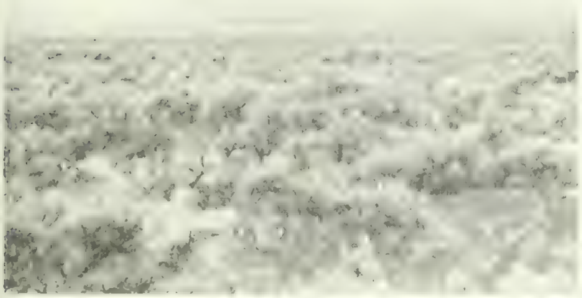

Figure 35.—Shadscale saltbush/bunchgrass community occurs on large expanses of the high deserts (Chris Maser photograph).

Average height of the grass-forb layer in this community is 14 centimeters (6 inches), ranging from 5 to 25 centimeters (2 to 10 inches). In most cases, total crown cover for the forb component is less than 1 percent (see footnote 5, p. 18). Dominance of the herbaceous layer varies between Sandberg bluegrass and bottlebrush squirreltail; average crown cover of each species is generally less than 5 percent. Sandberg bluegrass occurs in shrub interspaces and under shrub crowns; bottlebrush squirreltail, however, is found primarily under shrubs. The average height of Sandberg bluegrass, including seedstalks, is 10 centimeters (4 inches); that of bottlebrush squirreltail, 15 centimeters (6 inches). Cheatgrass, the only other grass present, has an average crown cover of less than 1 percent.

Forbs are sparse in this type. Only clasping pepperweed and Russianthistle are common. Crown cover is generally less than 5 percent and rarely exceeds 15 percent. Rare species are halogeton, wild buckwheat, and milkvetch.

Site

Most stands of this community occur on relatively level, lowland sites, but some are present on rolling topography. Slope varies from 0 to 30 percent among sites, directional aspect from north-northwest to south; the community is found on all slope positions. Macrorelief is level to moderately rolling hills, and microrelief is moderately smooth to moderately rough (see footnote 5, p. 18).

Soil

Soils are moderately deep, varying from silt loams to coarse gravelly and stony silt loams. Cobble and stone cover of the soil surface varies from 5 to 40 percent, with erosion pavement made up of coarse gravels that occupy small, low areas in shrub interspaces. In some lowland flats, dry soil surfaces in depression spots exhibit cracked and plated, polygonal patterns. Soil in all areas is strongly alkaline. In most areas, edges and bottoms of surface stone are encrusted with a thin calcareous layer (see footnote 5, p. 18).

Discussion

Vegetation in all stands appears to have had a long period of heavy use by livestock. Most perennial bunchgrass plants are present only under the protection of shrub crowns. The most common forbs are annual species (Russianthistle and clasping pepperweed) on abused ranges. Rodent burrows, mostly of kangaroo rats, are present in most sites but concentrated in areas of rolling, hilly relief. Mounds in these areas are large, 2 to 5 meters (7 to 16 ft) in diameter, and occur on ridges and slopes at a density up to 25 per hectare (10 per acre). Fewer and smaller mounds are found in bottoms and on flat topography. Small mounds of burrowing rodents are present on level areas with a density up to 12 per hectare (5 per acre). Large mounds vary from 4.5 to 6 meters (15 to 20 ft) in diameter and occur on flats at a density of approximately 10 per hectare (4 per acre).

The primary dispersal pattern of halogeton into the shadscale saltbush type in the Great Basin of Oregon is from highway shoulders and barrow pits to rodent mounds and other disturbed areas. From a survey of two 300-meter (985-ft) by 10-meter (33-ft) transects, beginning 10 meters from a highway shoulder and moving at a right angle to the road, only 2 halogeton plants were discovered in vegetation undisturbed by rodents, and 12 plants or small groups of plants were counted on rodent mounds. Frequency of halogeton fell off with distance from the highway.

Holmgren and Hutchings (1972) described shadscale saltbush as being palatable to livestock, but because of its spiny stems, use was limited to 15 to 20 percent of the previous season's growth. Bud sagebrush was generally palatable only in late winter, but it may be consumed all winter on occasion. It is considered more palatable for domestic sheep than for cattle. Russianthistle and cheatgrass are often abundant on heavily grazed shadscale saltbush ranges. These species are considered both palatable and nutritious by Holmgren and Hutchings (1972) but are undependable sources of forage because they are annuals.

Grassland Communities

The following natural communities dominated by grass and grasslike plants include seasonally wet and wet meadows, as well as subalpine grasslands. Shrubs and trees are either minor components or are absent from these communities.

26—SEASONALLY WET MEADOWS (figs. 36 and 37)

Vegetation

At low elevations, seasonally wet meadow vegetation is comprised primarily of grasses and sedges. Shrubs, such as willow, may occur in riparian situations adjacent to the type, or dry site shrubs may be present in stands on high ground or upslope at the dry edge of the type. Grasses include Kentucky bluegrass, Sandberg bluegrass, skyline bluegrass, Wheeler bluegrass, northern meadow barley, and spike trisetum. Sedges that may be present are smallwing, epapillous, Douglas, Liddon, slenderbeak, and Raynolds. Rushes generally occur as minor species; the most common in southeastern Oregon may be Drummond and swordleaf (Hansen 1956).

Hansen (1956) described shrubs in subalpine seasonally wet meadows on Steens Mountain as low weatherbeaten forms typical of windswept high mountain vegetation. Common shrubs (willows listed in appendix under "TREES") are Drummond willow, coyote willow, snow willow, bush cinquefoil, carthamoid goldenweed, and dwarf blueberry. Only four grass and grasslike species were reported—false-scirpus sedge, subnigricans sedge, winter bentgrass, and spreading woodrush. Forbs were more abundant: crag aster, elkslip marshmarigold, alpine shootingstar, Sierra willowweed, Watson willowweed, white bogorchid, oblongleaf bluebells, Rocky Mountain parnassia, lousewort, American bistort, Kellogg's knotweed, short-leaved cinquefoil, plainleaf buttercup, modest buttercup, roseroot stonecrop, and crisped starwort.

Figure 36.—Extensive seasonally wet meadows are shown with lesser amounts of permanently wet meadows along streams and around ponds.

Figure 37.—Seasonally ponded sumps at the western edge of the Great Basin generally dry up by mid-season. These areas are severely limited in production of forage.

Site

Seasonally wet meadows can occur in any vegetation zone in the high desert, from bottomlands of low elevation to subalpine ranges. Communities are present as either seasonally ponded or wet swales with no external drainage or as transitional stands between wet meadows and dryland shrub types (Dealy 1971). Where streams have been channeled because of erosion, wet meadows often have been permanently converted to either seasonally wet meadows or dryland shrub communities. In high precipitation zones or on sites where a subsurface lateral drainage emerges at valley edges (toe slopes), the seasonally wet grassland community often becomes prominent. Seasonal seeps, springs, and streams in any slope position often provide small stands of the community.

Soil

Seasonally wet meadows generally occur on moderately deep to deep clay or clay loam soils. Soils under meadows in good condition are high in organic matter and moisture-holding capacity. Wide cracks occur in the dry clay soils, producing a churning action (surface soil falls into cracks when the soil is dry and is incorporated at a lower level when soils become wet and cracks close) which mixes the upper horizons. Trampling of meadows by livestock during wet periods can result in soil damage and thus damage forage plants.

Discussion

Seasonally wet meadows are highly attractive to domestic and wild ungulates, and heavy grazing for more than 100 years has depleted vegetation of these stands. Sites large enough to provide substantial forage may be practical for intensive management of livestock. Small sites, however, such as near seasonal seeps and springs, may be best developed for wildlife but with water piped outside the protected habitat. Young tender forbs and grasses available into late spring contribute to optimum habitat for young grouse (Bump et al. 1947) and probably other gallinaceous birds. An oasis such as this is used by many wildlife species for food and cover.

27—PERMANENTLY WET MEADOWS (fig. 38)

Vegetation

Plant species composition of stands varies considerably among permanently wet sites on rangelands of the high desert. Grasses and sedges are typically dominant in meadows in good condition, and the forbs may also be abundant. At elevations below the subalpine zone, Hansen (1956) stated that whiplash willow was the most abundant shrub in meadows. Common grass and grasslike species were creeping bentgrass, northern meadow barley, mountain hairgrass, and ovalhead sedge. Columbia monkshood, primrose monkeyflower, and Scouler St. Johnswort were the most common forbs.

Figure 38.—Small areas of permanently wet meadows around seeps and springs are typical of the high desert mountains.

Site

Other than the large meadowlands on private holdings, wet meadow communities are found primarily as belts adjacent to riparian zones and as patches around perennial springs and seeps. They can be found on any aspect and most slopes, but those around springs and seeps may be more common on northerly aspects.

Discussion

Heavy grazing of most wet meadows for over 100 years has had a marked effect on the composition and productivity of these communities. Through recently developed manage-

ent practices, some riparian zones and adja-
nt wet meadows are being improved.[12] Small eas of meadow around springs and seeps ithin expanses of drier range may appear to uneconomical for management planning, t they are stands where livestock and ldlife concentrate. Because of their special lues for wildlife, it may be desirable to proct them to enhance the production of grasses, rbs, and shrubs and thus improve cover and rage for a wide variety of small animals and rds.

—SUBALPINE BUNCHGRASS
gs. 39 and 40)

Vegetation

Grassland communities of the subalpine ne are characterized by a dominant stand of scue, primarily sheep fescue (Maser and rickler 1978). Other grasses and grasslike ecies are rough fescue, prairie junegrass, sick bluegrass, longtongue mutton blueass, Sandberg bluegrass, and Dunhead sedge ansen 1956). Areas with disturbed soil conin small amounts of forbs (Hansen 1956).

Site

Hansen (1956) found the subalpine zone ove 2 439-meter (8,000-ft) elevation predomintly grassland interspersed with large areas bare windswept ground and the lower 244 eters (800 ft) overgrown to short sagebrush.

Discussion

Communities in subalpine regions are gile and can be severely damaged by liveck grazing and trampling. High winds and stable soils combined with severe grazing n produce rapid erosion of the surface layer grassland soils. Large, bare windswept areas probably a product of severe use by mestic sheep during the late 1800's and ly 1900's. Griffiths (1902) toured through theastern Oregon and referred to domestic eep use as extremely heavy. Vegetation was erely damaged. Griffiths (1902) noted large uds of dust caused by bands of domestic

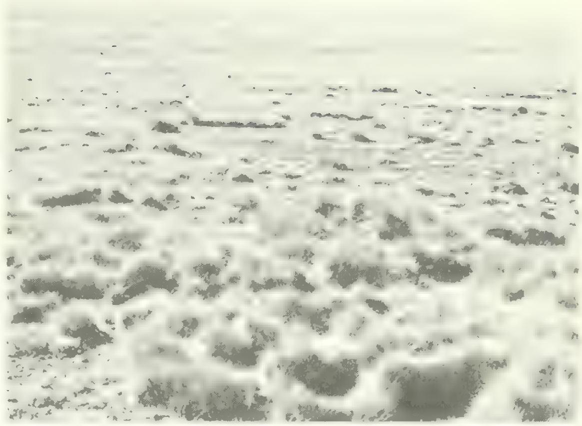

Figure 39.—Subalpine grassland of the high desert mountains; sheep fescue dominates the site (Chris Maser photograph).

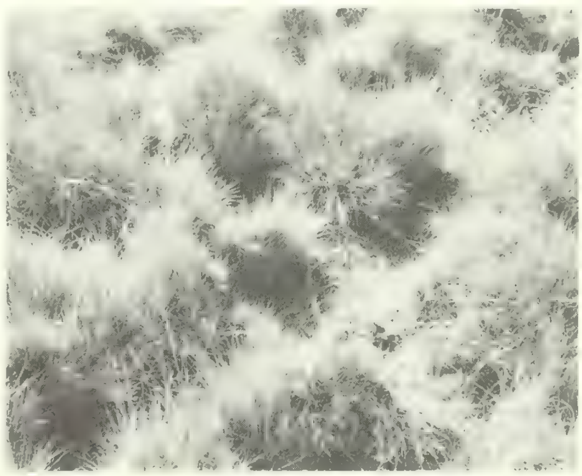

Figure 40.—Detailed view of a subalpine grassland; sheep fescue dominates the site (Chris Maser photograph).

sheep during the peak of the grazing season. Mule deer, pronghorns, bighorn sheep, and occasionally Rocky Mountain elk also use these high elevation areas.

Successional Vegetation

Successional patterns are highly complex in the communities of the northern Great Basin. Current composition of plant species can be misleading when site potential and suitable management alternatives are determined for various stands. Because of alterations by natural fire patterns and a long

rsonal communication, 1979, from Robert Kindschy, eau of Land Management, Vale, Oregon.

history of heavy use by livestock, there are relatively few communities or local stands in the desert rangelands that can be considered at or near climax condition. In other words, few stands are in a natural balance with the environment. The stands most difficult to identify are those that have been most severely altered.

Much work has been done to identify subspecies of big sagebrush (Beetle 1960, Beetle and Young 1965, Winward 1970, Winward and Tisdale 1977). Some of this work includes identification of typical soils and sites on which various subspecies are found. For example, Winward and Tisdale (1977), besides giving a taxonomic description of the subspecies, describe basin big sagebrush as growing "in deep, well drained soils of valley bottoms and lower foothill regions." They describe the occurrence of the subspecies in terms of elevation and response to disturbance. Recognition of subspecies and information on sites, along with soils and identification of remnant species that are characteristic of climax or advanced successional communities, can often help managers determine potential for a community.

The relationship between dominance of sagebrush and that of bunchgrass in climax shrub steppe communities is not understood. An excellent stand of grass dominated by bearded bluebunch wheatgrass or Idaho fescue and bearded bluebunch wheatgrass, either devoid of big sagebrush or having a small component of this shrub, may appear on the surface as a climax grassland community. That premise is usually not the case in the shrub steppe. Central and southeastern Oregon steppe communities devoid of a major shrub component are uncommon, and those that do appear as grasslands may have resulted from burning (Franklin and Dyrness 1973).

A brief examination of sites in question should help observers to correctly classify the stands. If topography, elevation, and soils in areas of question are similar to adjacent types with stands of shrubland communities, there is a greater than 90-percent chance that the questionable type is a shrub-grass climax in some stage of succession. Nearly complete destruction of the grass-forb layer under a shrub or tree-shrub-dominated stand can also make identification of plant communities difficult. Here, discovery of remnants of grass species and an analysis of site factors can help identify the original plant community.

An important key to developing a management outlook is recognizing ecological potential of the site—the potential of a community to support vegetation of interest. For example, Burkhardt and Tisdale (1969) presented strong evidence that with management and fire control in southwestern Idaho, western juniper has the potential to occupy the entire mountain big sagebrush/bunchgrass community. Given a site with this potential, a seed source, and barring fire or other repression of the trees and shrubs, the inevitable conclusion will be a western juniper/big sagebrush/bunchgrass stand. Similarly, given a potential sagebrush/bunchgrass community in a bunchgrass successional stage, the inevitable conclusion, barring inhibition of developing sagebrush, will be a shrub/grass community. With such knowledge built into management plans, managers will be spared the frustration of seeing "invasions" of shrubs or trees into communities considered stable "grass" types or "shrub/grass" types. The managers can then plan management strategies of stocking rates, season of use, manipulation of vegetation, and "preserved diversity" to suit established priorities based on the ecological realities of each site's potential.

The rate of successional advancement can vary greatly within any community. Experienced managers generally recognize and have a feel for this. A light fire that leaves scattered shrubs in a sagebrush type provides a ready seed source for reoccupancy by shrubs. A hot extensive fire, on the other hand, may virtually eliminate seed sources of shrubs over a great distance. Burning a south exposure shrub/grass community can produce microclimate conditions that may prevent reestablishment of shrubs for a long time. Such effects can be assessed and the information used in projecting future management alternatives.

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Appendix

Common and Scientific Names of Animals

Common name	Scientific name	Symbol[1]
	MAMMALS	
Badger	*Taxidea taxus*	
Beaver	*Castor canadensis*	
Bighorn sheep	*Ovis canadensis*	
Black-tailed jackrabbit	*Lepus californicus*	
Bushy-tailed woodrat	*Neotoma cinerea*	
Cattle	*Bos taurus*	
Coyote	*Canis latrans*	
Deer	*Odocoileus* sp.	
Domestic sheep	*Ovis aries*	
Domestic goat	*Capra* sp.	
Gophers	*Thomomys* sp.	
Ground squirrel	*Spermophilus* sp.	
Hare	*Lepus* sp.	
Kangaroo rat	*Dipodomys* sp.	
Mule deer	*Odocoileus hemionus*	
Pronghorn	*Antilocapra americana*	
Rabbit	*Sylvilagus* sp.	
Rocky Mountain elk	*Cervus elaphus*	
Vole	*Lagurus* sp.	
	BIRDS	
Geese	*Branta* sp.	
Horned lark	*Eremophila alpestris*	
Lark sparrow	*Chondestes grammacus strigatus*	
Sage grouse	*Centrocercus urophasianus*	
Sage sparrow	*Amphispiza belli*	
Swan	*Olor* sp.	

Common and Scientific Names and Symbols of Plants

	TREES	
Bittercherry	*Prunus emarginata*	PREM
Chokecherry	*Prunus virginiana*	PRVI
Cottonwood	*Populus* sp.	POPUL
Drummond willow	*Salix drummondiana*	SADR
Fir	*Abies* sp.	ABIES
Juniper	*Juniperus* sp.	JUNIP
Ponderosa pine	*Pinus ponderosa*	PIPO
Quaking aspen	*Populus tremuloides*	POTR
Spruce	*Picea* sp.	PICEA
Western juniper	*Juniperus occidentalis*	JUOC
White fir	*Abies concolor*	ABCO

[1]After Garrison et al. (1976).

ppendix (continued)

Common name	Scientific name	Symbol[1]
	SHRUBS	
telope bitterbrush	*Purshia tridentata*	PUTR
sin big sagebrush	*Artemisia tridentata* subsp. *tridentata*	ARTRT
g sagebrush	*Artemisia tridentata*	ARTR
ack greasewood	*Sarcobatus vermiculatus*	SAVE2
ack sagebrush	*Artemisia nova*	ARNO2
lander silver sagebrush	*Artemisia cana* subsp. *bolanderi*	ARCAB
oom snakeweed	*Gutierrezia sarothrae*	GUSA
d sagebrush	*Artemisia spinescens*	ARSP
sh cinquefoil	*Potentilla fruticosa*	POFR
rthamoid goldenweed	*Haplopappus carthamoides*	HACA
ftleaf sagebrush	*Artemisia arbuscula* subsp. *thermopola*	ARART
yote willow	*Salix exigua*	SAEX
eeping Oregon grape	*Berberis repens*	BERE
rlleaf mountainmahogany	*Cercocarpus ledifolius ledifolius*	CELEL
sert rockspirea	*Holodiscus dumosus*	HODU
varf blueberry	*Vaccinium caespitosum*	VACA
varf threetip sagebrush	*Artemisia tripartita* subsp. *rupicola*	ARTRR
rly low sagebrush	*Artemisia longiloba*	ARLO2
ldenweed	*Haplopappus* sp.	HAPLO2
anite gilia	*Leptodactylon pungens*	LEPU
ay horsebrush	*Tetradymia canescens*	TECA
ay rabbitbrush	*Chrysothamnus nauseosus*	CHNA
een rabbitbrush	*Chrysothamnus viscidiflorus*	CHVI
psage	*Grayia*	GRAYI
rsebrush	*Tetradymia sp.*	TETRA
w sagebrush	*Artemisia arbuscula* subsp. *arbuscula*	ARARA
untain big sagebrush	*Artemisia tridentata* subsp. *vaseyana*	ARTRV
untain silver sagebrush	*Artemisia cana* subsp. *viscidula*	ARCAV
untain snowberry	*Symphoriocarpus oreophilus*	SYOR
bbitbrush	*Chrysothamnus* sp.	CHRYS3
gebrush	*Artemisia* sp.	ARTEM
katoon serviceberry	*Amelanchier alnifolia*	AMAL
dscale saltbush	*Atriplex confertifolia*	ATCO
ver sagebrush	*Artemisia cana*	ARCA
ow willow	*Salix nivalis*	SANI
ny hopsage	*Grayia spinosa*	GRSP
aw apple	*Peraphyllum ramosissimum*	PERA3
ff sagebrush	*Artemisia rigida*	ARRI
balpine big sagebrush	*Artemisia tridentata* form *spiciformis*	ARTRS
eetip sagebrush	*Artemisia tripartita*	ARTR2
x currant	*Ribes cereum*	RICE
iplash willow	*Salix caudata*	SACA
llow	*Salix* sp.	SALIX
oming big sagebrush	*Artemisia tridentata* subsp. *wyomingensis*	ARTRW

[1]ter Garrison et al. (1976).

Appendix (continued)

Common name	Scientific name	Symbol[1]
	GRASS AND GRASSLIKE PLANTS	
Baltic rush	*Juncus balticus*	JUBA
Bearded bluebunch wheatgrass	*Agropyron spicatum*	AGSP
Big bluegrass	*Poa ampla*	POAM
Blue wildrye	*Elymus glaucus*	ELGL
Bottlebrush squirreltail	*Sitanion hystrix*	SIHY
California brome	*Bromus carinatus*	BRCA
Cheatgrass	*Bromus tectorum*	BRTE
Creeping bentgrass	*Agrostis palustris*	AGPA
Crested wheatgrass	*Agropyron desertorum*	AGDE
Cusick bluegrass	*Poa cusickii*	POCU
Cutting wheatgrass	*Agropyron caninum*	AGCA
Desert saltgrass	*Distichlis stricta*	DIST
Douglas sedge	*Carex douglasii*	CADO
Drummond rush	*Juncus drummondii*	JUDR
Dunhead sedge	*Carex phaeocephala*	CAPH
Dwarf squirreltail	*Sitanion hystrix* var. *hordeoides*	SIHYH
Epapillous sedge	*Carex epapillosa*	CAEP
False-scirpus sedge	*Carex scirpoidea* var. *pseudoscirpoidea*	CASCP
Fescue	*Festuca* sp.	FESTU
Giant wildrye	*Elymus cinereus*	ELCI
Green fescue	*Festuca viridula*	FEVI
Hairgrass	*Deschampsia* sp.	DESCH
Idaho fescue	*Festuca idahoensis*	FEID
Indian ricegrass	*Oryzopsis hymenoides*	ORHY
Intermediate wheatgrass	*Agropyron intermedium*	AGIN2
Kentucky bluegrass	*Poa pratensis*	POPR
Lemmon needlegrass	*Stipa lemmonii*	STLE2
Liddon sedge	*Carex petasata*	CAPE
Longtongue mutton bluegrass	*Poa longiligula*	POLO
Medusahead wildrye	*Elymus caput-medusae*	ELCA2
Mountain hairgrass	*Deschampsia atropurpurea*	DEAT
Muhly	*Muhlenbergia richardsonis*	MURI
Needleandthread	*Stipa comata*	STCO2
Needlegrass	*Stipa* sp.	STIPA
Nevada bluegrass	*Poa nevadensis*	PONE2
Northern meadow barley	*Hordeum brachyantherum*	HOBR
One-spike oatgrass	*Danthonia unispicata*	DAUN
Oniongrass	*Melica* sp.	MELIC
Ovalhead sedge	*Carex festivella*	CAFE
Pacific fescue	*Festuca pacifica*	FEPA
Pinegrass	*Calamagrostis rubescens*	CARU
Prairie junegrass	*Koeleria cristata*	KOCR
Raynolds sedge	*Carex raynoldsii*	CARA
Ross sedge	*Carex rossii*	CARO
Rough fescue	*Festuca scabrella*	FESC
Rush	*Juncus* sp.	JUNCU
Sandberg bluegrass	*Poa sandbergii*	POSA3
Sedge	*Carex* sp.	CAREX
Sheep fescue	*Festuca ovina*	FEOV
Skyline bluegrass	*Poa epilis*	POEP
Slenderbeak sedge	*Carex athrostachya*	CAAT
Slender wheatgrass	*Agropyron trachycaulum*	AGTR

[1]After Garrison et al. (1976).

pendix (continued)

Common name	Scientific name	Symbol[1]
allwing sedge	*Carex microptera*	CAMI
ooth brome	*Bromus inermis*	BRIN
ke rush	*Eleocharis* sp.	ELEOC
ke trisetum	*Trisetum spicatum*	TRSP
eading woodrush	*Luzula divaricata*	LUDI
nigricans sedge	*Carex subnigricans*	CASU5
ordleaf rush	*Juncus ensifolius*	JUEN
eadleaf sedge	*Carex filifolia*	CAFI
irber needlegrass	*Stipa thurberiana*	STTH
nothy	*Phleum pratense*	PHPR
stern needlegrass	*Stipa occidentalis*	STOC
eatgrass	*Agropyron* sp.	AGROP
eeler bluegrass	*Poa nervosa*	PONE
nter bentgrass	*Agrostis scabra*	AGSC
	FORBS	
ska habenaria	*Habenaria unalascensis*	HAUN
ine shootingstar	*Dodecatheon alpinum*	DOAL
erican bistort	*Polygonum bistortoides*	POBI
nual agoseris	*Agoseris heterophylla*	AGHE
owleaf balsamroot	*Balsamorhiza sagittata*	BASA
ny penstemon	*Penstemon humilis*	PEHU
er	*Aster* sp.	ASTER
um willowweed	*Epilobium paniculatum*	EPPA
samroot	*Balsamorhiza* sp.	BALSA
kwith violet	*Viola beckwithii*	VIBE
lstraw	*Galium* sp.	GALIU
thistle	*Eryngium articulatum*	ERAR
head clover	*Trifolium macrocephalum*	TRMA
uitroot	*Lomatium* sp.	LOMAT
omer fleabane	*Erigeron bloomeri*	ERBL
-orchid	*Habenaria* sp.	HABEN
kwheat	*Eriogonum caespitosum*	ERCA
quefoil	*Potentilla* sp.	POTEN
ping pepperweed	*Lepidium perfoliatum*	LEPE
mbia monkshood	*Aconitum columbianum*	ACCO
bleaf	*Polyctenium fremontii*	POFR2
mon dandelion	*Taraxicum officianale*	TAOF
aster	*Aster scopulorum*	ASSC
ped starwort	*Stellaria crispa*	STCR
gerpod	*Phoenicaulis cheiranthoides*	PHCH
delion	*Taraxicum* sp.	TARAX
rf hesperochiron	*Hesperochiron pumilis*	HEPU
rf monkeyflower	*Mimulus nanus*	MINA
lip marshmarigold	*Caltha leptosepala*	CALE2
e agoseris	*Microseris troximoides*	MITR
e hellebore	*Veratrum* sp.	VERAT
bane	*Erigeron* sp.	ERIGE
penstemon	*Penstemon laetus*	PELA
hawksbeard	*Crepis intermedia*	CRIN
's biscuitroot	*Lomatium grayi*	LOGR
geton	*Halogeton glomeratus*	HAGL
ksbeard	*Crepis* sp.	CREPI
tleaf arnica	*Arnica cordifolia*	ARCO

[1] r Garrison et al. (1976).

Appendix (continued)

Common name	Scientific name	Symbol[1]
Holboell rockcress	*Arabis hoelboellii*	ARHO
Hood's phlox	*Phlox hoodii*	PHHO
Hooker balsamroot	*Balsamorhiza hookeri*	BAHO
Kellogg's knotweed	*Polygonum kelloggii*	POKE
Lambstongue groundsel	*Senecio integerrimus*	SEIN
Locoweed	*Astragalus* sp.	ASTRA
Longleaf phlox	*Phlox longifolia*	PHLO
Lousewort	*Pedicularis attollens*	PEAT
Low pussytoes	*Antennaria dimorpha*	ANDI
Lupine	*Lupinus* sp.	LUPIN
Meadowrue	*Thalictrum* sp.	THALI
Milkvetch	*Astragalus* sp.	ASTRA
Modest buttercup	*Ranunculus verecundus*	RAVE
Nevada biscuitroot	*Lomatium nevadenses*	LONE
Newberry cinquefoil	*Potentilla newberryi*	PONE3
Nineleaf biscuitroot	*Lomatium triternatum*	LOTR
Nuttall violet	*Viola nuttallii*	VINU
Oblongleaf bluebells	*Mertensia obligifolia*	MEOB
Obscure milkvetch	*Astragalus obscurus*	ASOB
Peavine	*Lathyrus* sp.	LATHY
Phlox	*Phlox* sp.	PHLOX
Pink microsteris	*Microsteris gracilis*	MIGR
Plainleaf buttercup	*Ranunculus alismaefolius*	RAAL
Prairiesmoke avens	*Geum triflorum*	GETR
Primrose monkeyflower	*Mimulus primuloides*	MIPR
Pussytoes	*Antennaria* sp.	ANTEN
Rockcress	*Arabis* sp.	ARABI
Rocky Mountain parnassia	*Parnassia fimbriata*	PAFI
Roseroot stonecrop	*Sedum roseum*	SERO
Russianthistle	*Salsola kali*	SAKA
Scouler St. Johnswort	*Hypericum scouleri*	HYSC
Short-leaved cinquefoil	*Potentilla brevifolia*	POBR
Showy downingia	*Downingia elegans*	DOEL
Sierra willowweed	*Epilobium brevistylum*	EPBR
Skyrocket gilia	*Gilia aggregata*	GIAG
Slenderbush eriogonum	*Eriogonum microthecum*	ERMI
Sorrel	*Rumex* sp.	RUMEX
Spreading phlox	*Phlox diffusa*	PHDI
Spring draba	*Draba verna*	DRVE2
Spur lupine	*Lupinus laxiflorus*	LULA2
Starved milkvetch	*Astragalus miser*	ASMI
Stenophyllus pussytoes	*Antennaria stenophylla*	ANST
Stinging nettle	*Urtica dioica*	URDI
Tapertip hawksbeard	*Crepis acuminata*	CRAC
Thistle	*Cirsium* sp.	CIRSI
Tiny mousetail	*Myosurus minimus*	MYMI2
Varileaf phacelia	*Phacelia heterophylla*	PHHE
Violet	*Viola* sp.	VIOLA
Watson willowweed	*Epilobium watsonii*	EPWA
Western hawkweed	*Hieraceum albertinum*	HIAL2
White bogorchid	*Habenaria dilatata*	HADI2
Wild buckwheat	*Eriogonum* sp.	ERIOG
Woodlandstar	*Lithophragma bulbifera*	LIBU
Woolly eriophyllum	*Eriophyllum lanatum*	ERLA
Wyeth eriogonum	*Eriogonum heracleoides*	ERHE
Yarrow	*Achillea millefolium*	ACMI

[1]After Garrison et al. (1976).

WILDLIFE HABITATS IN MANAGED RANGELANDS — THE GREAT BASIN OF SOUTHEASTERN OREGON

Technical Editors

JACK WARD THOMAS, U.S. Department of Agriculture, Forest Service

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Report
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Silviculture of Mixed Conifer Forests in Eastern Oregon and Washington

K.W. Seidel and P.H. Cochran

Authors

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ABSTRACT

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The silviculture of mixed confier forests in eastern Oregon and Washington is described. Topics discussed include ecological setting, damaging agents, silviculture, and management. The relevant literature is presented, along with unpublished research, experience, and observations. Research needs are also proposed.

Keywords: Silviculture, mixed stands, coniferae, timber management, regeneration (stand), eastern Oregon, eastern Washington.

CONTENTS

NTRODUCTION

Timber management research in the mixed conifer forests of eastern Oregon and Washington has been under way for only about 10 years. During this period the results of studies on the silvics and silviculture of mixed conifer forests have been reported in a number of publications. This paper summarizes the available knowledge on timber management in these forests based on past research, work done in adjacent areas having similar forest types, and observations and experience of land managers. From this information, general guidelines and recommendations for silvicultural prescriptions have been developed. Although much has been learned about the characteristics and management of these mixed conifer forests, much remains to be learned. Because of the complex nature of these forests and the relatively limited available knowledge, recommendations are often tentative.

This paper is intended as a guide for professional foresters and land managers who are responsible for prescribing and supervising the application of silvicultural treatments in mixed conifer forests. No attempt is made to discuss all possible silvicultural alternatives. Rather, the objective is to present a broad overview of the state of the art. Recommendations must be modified in response to local ecological, economic, and social conditions, and as additional facts and experience are accumulated.

;ENERAL)ESCRIPTION)F MIXED CONIFER 'ORESTS

The mixed conifer forests of eastern Oregon and Washington occupy a great variety of landforms (fig. 1). For purposes of this report, mixed conifer forests are considered to consist of all forests other than pure ponderosa pine,[1] pure lodgepole pine, or mixtures of ponderosa and lodgepole pines. Commercial mixed conifer stands east of the Cascade summit in Oregon and Washington occur within parts of the Okanogan Highlands, the Northern Cascades, the Southern Washington Cascades, the Blue Mountains, the High Cascades, the High Lava Plains, and the Basin and Range Physiographic Provinces (fig. 2). These mixed conifer forests contain a large number of species whose seedlings are less tolerant to drought than ponderosa pine and therefore occupy higher elevation sites where moisture is more readily available. Species common in these mixed conifer forests include Douglas-fir, ponderosa pine, western larch, lodgepole pine, grand fir, white fir, subalpine fir, western white pine, Engelmann spruce, Shasta red fir, mountain hemlock, western hemlock, and western red cedar.

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[1]Scientific names of plants and animals mentioned are listed on page 69, appendix.

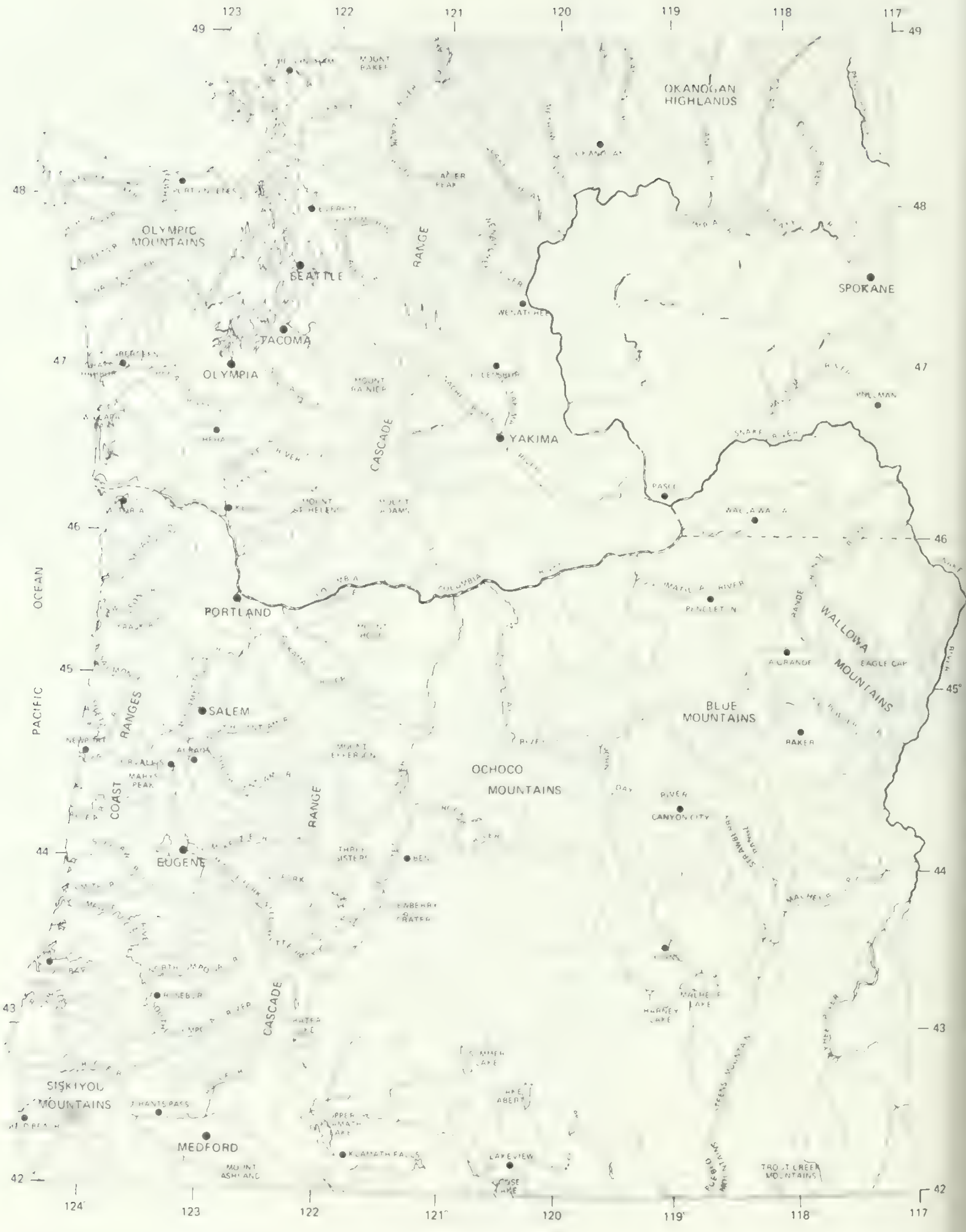

Figure 1.—Major topographic features and some cities and towns in Oregon and Washington. (Reproduced from Franklin and Dyrness 1973.)

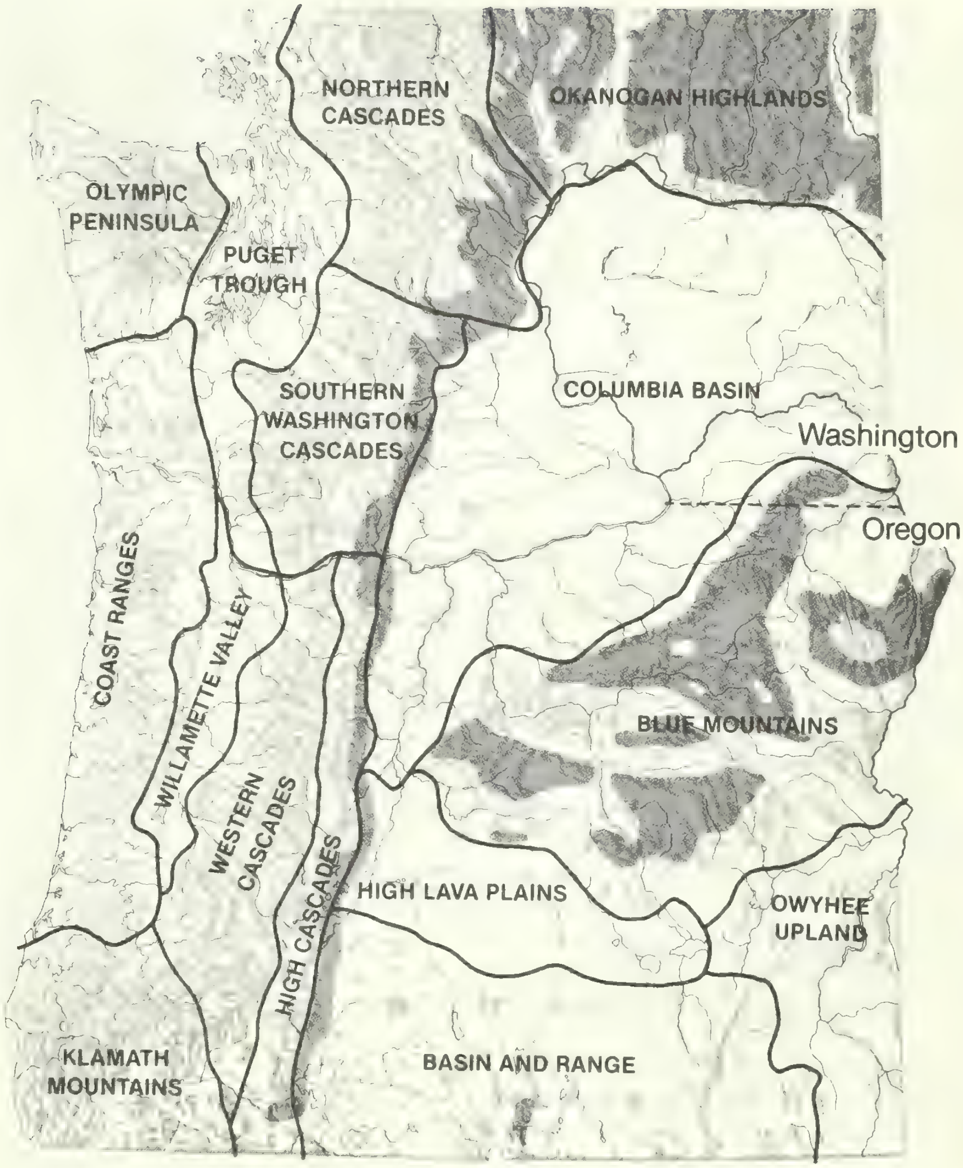

Figure 2.—Physiographic and geological provinces in Oregon and Washington. The distribution of mixed conifer forests is shown by the shaded area. (Adapted from Franklin and Dyrness 1973.)

Stand structure and species composition are extremely variable depending upon site, logging history, insect and disease attacks, and wildfire. Various combinations of species are found growing together in both even-aged and uneven-aged stands. As a result of past fires, many of these forests consist of a mosaic of even-aged stands (or at least two- or three-aged), with even-aged overstories and one or two age classes in the understory. Uneven-aged stands having a multi-storied structure are also common. At lower elevations, mixtures of ponderosa pine and Douglas-fir occur. Farther up the slope, larch and lodgepole pine, both seral[2] species in these forests, are found in pure or mixed stands as a result of fire or clearcutting. In many such stands, an understory of Douglas-fir or grand fir is common. At higher elevations, mountain hemlock and subalpine fir are the climax vegetation.

Lodgepole pine is seral in the forests of eastern Oregon and Washington except on the pumice plateau of central Oregon, where it is found in pure stands in the pine type and is considered an edaphic or topoedaphic climax[3] because of its ability to survive on more severe sites where there is little competition and temperature extremes are common. These climax lodgepole stands are not considered in this report.

ECOLOGICAL SETTING

Climate

Eastern Oregon and Washington have a more continental climate than areas west of the Cascade Range. Typical weather patterns consist of cold winters, hot and dry summers, and large diurnal temperature fluctuations. Precipitation is primarily cyclonic as a result of low-pressure systems from the Pacific Ocean but is much less than to the west because the area lies in the rain shadow of the Cascade Range. Much of the annual precipitation falls as snow and the frost-free season is relatively short. Elevation of the mountain areas within the region is the primary factor influencing local climate. Temperatures decrease and precipitation increases rapidly with increasing elevation. This, of course, has a profound effect on the vegetation. Species better adapted to a cold and moist environment are found at higher elevations while those more tolerant of warm and dry conditions become established at lower elevations.

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[2]Species in the early or developmental stages of a plant community before the climax or equilibrium condition.

[3]Edaphic climax: a plant community that differs from the normal climatic climax because of abnormal soil conditions. Topoedaphic climax: a plant community that differs from the normal climatic climax because of abnormal soil conditions and special microclimates resulting from local topography.

Soils

In the Okanogan Highlands, deposits of glacial drift are widespread. In some of the main valleys, glaciolacustrine sediments form a series of terraces on valley walls. In mountainous areas away from the major river valleys, forested soils derived from granitic parent material are Xerochrepts and Cryorthods. Soils at high elevations developing over glacial materials often have high volcanic ash content and are Vitrandepts or Cryandepts. Soils at lower elevations on terraces and flood plains along major rivers are usually coarse textured, well to excessively drained, and classified as Haploxerolls, Vitrandepts, Haplorthods, and Xeropsamments.

The Northern Cascades are characterized by extreme variability in parent materials, extensive glaciation, and steep slopes. Most of the forested soils east of the divide are Vitrandepts, Cryandepts, Cryorthods and Haplorthods with some Xerochrepts and Haploxerolls at lower elevations.

Andesite and basalt flows with associated breccias and tuffs dominate the Southern Washington Cascades Province. East of the Cascade crest, soils are largely Vitrandepts, Xerochrepts, Cryandepts, with Haploxeralfs and Haploxerolls at lower elevations. These soils, although derived primarily from andesite, sandstone, or glacial till, are also influenced to a considerable extent by volcanic ash or loess or both. Soil textures are often silt loams or loams.

Much of the area within the central and northern portions of the Blue Mountains was covered by a layer of aerially deposited volcanic ash and fine pumice ejected from Mount Mazama (Crater Lake) about 6,500 years ago. Subsequent erosion has largely removed the ash from south-facing slopes; however, other locations are typically mantled by the material. Many upland areas were covered by loess deposits. Forested soils developing on volcanic ash are almost completely restricted to broad ridge tops and north-facing slopes where the ash mantle varies from 2 to 3 feet. Most of these soils are Vitrandepts and Cryandepts. In ashless areas the soils are mostly Haploxerolls and Argixerolls.

The High Cascades Province is dominated by immature soils developed in volcanic ejecta and soils showing more profile development which are derived from glacially deposited materials. The forested soils of the northern section are dominated by Cryorthods and Cryumbrepts. The southern areas have extensive mantles of volcanic ejecta (pumice, cinders, and ash) and the soils are mostly Cryorthents and Cryandepts.

Mixed conifer forests occur in the western portion of the High Lava Plains Province adjacent to the High Cascades Province. Soils beneath these forests are developing from pumice and are classified as Cryorthents.

Commercial mixed conifer forests occur in the western portion of the Basin and Range Province and in the central portion of the Province in the Warner Mountains where the dominant soils are Cryoborolls. The immature soils in the western portion are strongly influenced by Mazama pumice north of the Sprague River and are Cryorthents and Cryoborolls.

Vegetation

The diversity of habitats in the mixed conifer forests of eastern Oregon and Washington is evident to even the casual observer, but only recently has the basic biological and ecological information needed to understand and classify the vegetational associations of these forests begun to accumulate. Natural vegetation can be classified and organized in many ways. Franklin and Dyrness (1973) have provided a detailed description of the plant geography and ecology of these complex, mixed conifer forests in their comprehensive account of the natural vegetation of Oregon and Washington. Our purpose here is to briefly describe the dominant vegetation in terms of timber or cover types, forest zones, and plant communities.

Timber or Cover Types.—Timber types simply classify existing forest vegetation in terms of predominant tree species with no implication as to whether the species are temporary or relatively stable. The principal mixed conifer forest cover types of eastern Oregon and Washington (Society of American Foresters 1980) are:

Type Number	Type
205	Mountain hemlock-subalpine fir
206	Engelmann spruce-subalpine fir
207	Red fir
210	Interior Douglas-fir
211	White fir
212	Western larch
213	Grand fir

Forest Zones.—Classification of forests by altitudinal-vegetation zones in mountainous regions is a common way of differentiating natural vegetation (Daubenmire 1943, 1946). Such zones have been based on climate, existing vegetation, and potential (climax) vegetation. The forest zones identified by Franklin and Dyrness (1973) are based on communities in which a single tree species is the major climax dominant. They point out some characteristics of this zonal scheme as follows:

1. Zones may occur as sequential belts on mountain slopes, but generally they interfinger, with each attaining its lower elevational limits in valleys and its highest limits on ridges.
2. There is a tendency for species or associations occupying modal sites in one zone to occur on moist, cool habitats in the adjacent warmer and drier zone and on warm, dry habitats in the adjacent cooler and moister zone.
3. Disturbance and the resulting seral vegetation may obscure zonal sequences. Pioneer species often range throughout several zones. Many of the seral dominants in a given zone tend to be climax species in adjacent warmer and drier zones.
4. Zonal schemes reflect plant responses to strong macroclimatic gradients in temperature and moisture. Unusual soil properties sometimes override climatic factors to severely modify zonation patterns. The pumice plateau region of central Oregon is an example of this condition.

The *Pseudotsuga menziesii* zone is the lowest elevational zone in the mixed conifer forests of eastern Oregon and Washington. It is well developed in most of eastern Washington at an elevation of 2,000 - 4,300 feet. In eastern Oregon it is sparse or absent except in parts of the Wallowa Mountains. Douglas-fir, ponderosa pine, lodgepole pine, and western larch are the major species (table 1). This zone is more mesic than those at lower elevations.

Table 1—Importance and ecological role of major tree species in representative forest zones and locales in eastern Oregon and Washington[1]

	Eastern Washington Cascade Range					Central Oregon Cascade Range					Ochoco and Blue Mountains		Southern Oregon Cascade Range		
Species	*Pinus ponderosa* Zone	*Pseudotsuga menziesii* Zone	*Abies grandis* Zone	*Tsuga heterophylla* Zone	*Abies lasiocarpa* Zone	*Juniperus occidentalis* Zone	*Pinus ponderosa* Zone	*Pseudotsuga menziesii* Zone	*Abies grandis*[2] Zone	*Tsuga mertensiana* Zone	*Pinus ponderosa* Zone	*Abies grandis*[2] Zone	*Pinus contorta* Zone	*Pinus ponderosa* Zone	*Abies concolor* Zone
Abies amabilis	—	—	—	—	c	—	—	—	—	c	—	—	—	—	—
Abies grandis or *concolor*	—	—	C	S	s	—	—	—	C	s	—	C	—	—	C
Abies lasiocarpa	—	—	—	s	C	—	—	—	s	C	—	—	—	—	—
Abies magnifica shastensis	—	—	—	—	—	—	—	—	—	—	—	—	—	—	s
Libocedrus decurrens	—	S	S	s	s	—	—	c	s	—	—	—	—	—	s
Larix occidentalis	—	S	S	s	s	—	—	s	s	—	—	S	—	—	—
Larix lyallii	—	—	—	—	s	—	—	—	—	—	—	—	—	—	—
Picea engelmannii	—	—	s	s	Sc	—	—	—	s	s	—	s	—	—	—
Pinus contorta	—	S	S	s	s	—	—	s	S	S	—	S	C	S	s
Pinus lambertiana	—	—	—	—	—	—	—	—	s	—	—	—	—	—	s
Pinus monticola	—	—	S	S	s	—	—	—	s	s	—	s	—	—	s
Pinus ponderosa	C	S	S	s	—	—	C	S	S	s	C	s	c	C	S
Juniperus occidentalis	—	—	—	—	—	C	s	s	—	—	s	—	—	s	—
Populus tremuloides	s	s	s	—	—	—	s	s	s	—	—	—	s	s	s
Pseudotsuga menziesii	—	C	S	S	s	—	—	C	S	s	—	Sc	—	—	—
Thuja plicata	—	—	—	sc	—	—	—	—	—	—	—	—	—	—	—
Tsuga heterophylla	—	—	—	C	s	—	—	—	—	—	—	—	—	—	—
Tsuga mertensiana	—	—	—	—	c	—	—	—	s	C	—	—	—	—	s

[1]C = major climax species, c = minor climax species, S = major seral species, and s = minor seral species.

[2]*Abies grandis-A. concolor* complex.

Source: Franklin and Dyrness (1973).

The *Abies grandis* zone is the most extensive midslope zone in the Cascade Range of Oregon and southern Washington and the Blue Mountains of eastern Oregon. It is generally found at 3,600 - 4,900 feet in the central Oregon Cascades, 4,900 - 6,500 feet in the Ochoco and Blue Mountains, and 5,400 - 6,500 feet in south-central Oregon. Principal tree species are grand fir or white fir,[4] ponderosa pine, lodgepole pine, western larch, and Douglas-fir. Climatic conditions are moderate with more precipitation and cooler temperatures than in lower zones.

The *Tsuga heterophylla* zone is an eastern extension of the coastal western hemlock zone and is found on the eastern slopes of the Cascades in Washington and northern Oregon at elevations between 2,600 and 3,900 feet. This zone also occurs in the mountains of the Okanogan Highlands. Major tree species, in addition to those in the *Pseudotsuga menziesii* and *Abies grandis* zones are western white pine, western red cedar, and western hemlock. This zone has the best tree-growing climatic regime of all the interior forest zones.

The subalpine forests of eastern Oregon and Washington are represented by the *Abies lasiocarpa* and *Tsuga mertensiana* zones. The *Abies lasiocarpa* zone is found on high secondary ranges extending east from the crest of the Washington Cascades, in the Okanogan Highlands, and in the Blue and Wallowa Mountains. The *Tsuga mertensiana* zone is the highest forested zone along the western slopes and crest of the Cascade Range but also extends east of the Cascade crest where it merges with the interior *Abies lasiocarpa* zone. Extensive mountain hemlock forests occur east of the Cascade crest in central and southern Oregon. Major species in these zones are subalpine fir, mountain hemlock, Engelmann spruce, and lodgepole pine. True firs are also common. These are the coolest and wettest of the forest zones with short, cool summers and long, cold winters. Much of the precipitation falls as snow which accumulates to depths of 26 feet and remains on the ground for 6 to 8 months of the year.

Habitat Types or Plant Communities.—Within each of the forest zones identified in the mixed conifer forests of eastern Oregon and Washington, there is a wide range of environmental conditions, and the response to a given silvicultural treatment may vary considerably within the same zone. Therefore, it is desirable to identify natural landscape units which are relatively uniform in biological and physical characteristics. In the western United States, identification of these relatively homogenous units has been accomplished in many areas by habitat types or plant communities. A habitat type is based on the potential climax vegetation in terms of the self-perpetuating tree species and the dominant understory species. It provides an ecologically sound integration of the various environmental factors as expressed in the climax vegetation. Thus, the land manager can have greater assurance that similar treatments on the same habitat type will give similar results.

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[4]Grand fir and white fir form a continuously varying biological complex in eastern Oregon. For management purposes, grand and white fir can be treated alike.

Considerable progress has been made in identifying habitat types in the mixed conifer forests of eastern Oregon and Washington. In northern Idaho and northeastern Washington, Daubenmire and Daubenmire (1968) identified 21 habitat types: 6 in the ponderosa pine type and 15 in mixed conifer zones. In the Blue Mountains, Hall (1973) identified 45 plant communities, ranging from grass/sagebrush habitats to subalpine types, and gave estimates of site potential for range and timber management. Volland (1976) working in the central Oregon pumice zone, described 61 habitat types and also gave estimates of various characteristics of these communities which affect land management. And Hopkins (1979a, 1979b) identified plant communities in the Fremont and Winema National Forests in south-central Oregon.

Climax and Succession

In the absence of disturbance on mixed conifer sites, natural succession will result in the replacement of seral communities by the more shade tolerant climax species. These climax species will tend to persist until severe disturbance, such as fire, clearcutting, windthrow, or insects and diseases, creates conditions favorable for establishment of intolerant species. Thus, western larch and lodgepole pine, both seral species in the *Abies grandis* zone, are commonly found in even-aged stands resulting from fire or clearcutting. In many areas of the mixed conifer forests, severe disturbance can result in grass and shrub communities if tree regeneration is not established immediately. Gratkowski (1974) estimated that 1,482,600 acres of mixed conifer forest land is occupied by species such as snowbrush ceanothus, Sierra evergreen chinkapin, greenleaf manzanita, and willows. Once these species become dominant, conifers may be excluded for decades unless expensive measures are taken to reforest the site artificially.

The classical concept of succession as a more or less orderly process proceeding from less shade tolerant pioneer species to the more tolerant climax species is useful in looking at various plant communities and predicting changes that will result from management activities. In general, these successional changes do occur over much of the mixed conifer forests. The silviculturist should be aware, however, that exceptions also occur because of availability of seed or local site conditions. For example, because of an adequate seed supply, an intolerant and a tolerant species may invade a disturbed area simultaneously. Differences in tree size apparent many years later may be caused by differences in growth rates of the two species rather than later establishment of the more tolerant species.

Successional trends within forest zones and plant communities have important implications for forest management. Observations suggest the following order of shade tolerance, from most to least tolerant species: western hemlock ≈ western red cedar > mountain hemlock ≈ subalpine fir ≈ Engelmann spruce ≈ grand or white fir > Douglas-fir > western white pine ≈ ponderosa pine ≈ lodgepole pine > western larch. In order to successfully apply selected silvicultural systems, however, it is essential to realize that the successional role or relative tolerance of species differs from site to site. For example, Douglas-fir is the climax species in the *Pseudotsuga menziesii* zone but a seral species in the *Abies grandis* zone. Therefore, application of uneven-aged management (selection system) in the *Pseudotsuga menziesii* zone would tend to maintain Douglas-fir in the stand whereas it would be replaced by more tolerant species in the *Abies grandis* zone.

PRINCIPAL DAMAGING AGENTS

Insects

Mixed conifer forests are attacked by a large number of insect pests (Furniss and Carolin 1977). Those causing serious damage over large areas include the Douglas-fir beetle, the mountain pine beetle, the Douglas-fir tussock moth, the western spruce and Modoc budworms, the larch casebearer, the fir engraver, and the pine engraver.

The Douglas-fir beetle is the most damaging bark beetle pest of Douglas-fir throughout the range of this tree. Generally, it breeds in felled, damaged, or diseased trees, and large populations can kill many mature and overmature trees (Furniss and Orr 1970). When outbreaks occur, usually following blowdown or defoliation by other insects, nearly every Douglas-fir in a stand can be killed. Direct control of the beetle has seldom been attempted and is not recommended. Research with a pheromone, however, suggests a possible control measure for the future (Furniss et al. 1974). In interior forests, preventive control is obtained by thinning and harvesting.

The mountain pine beetle is the most destructive bark beetle in the western States. It attacks all pine species but causes most damage to overmature or overstocked stands of ponderosa and lodgepole pine and can be a serious problem in mixed conifer forests where these species are major components. Details of the life history of the mountain pine beetle and the damage it causes are given by Evenden et al. (1943) and McCambridge and Trostle (1972). During endemic infestations beetles favor weaker, less vigorous trees for attack, but no such selection occurs during epidemics. Attacks are recognized by pitch tubes that are usually heaviest along the main bole of the tree from the ground to midcrown. Sometimes a heavy flow of resin from the tree will prevent successful attacks by the beetle. Various methods to control epidemics have been attempted, such as felling and burning or peeling, and treating with oil or chemical sprays, but such measures are generally uneconomical and of limited usefulness because large areas are involved. Control by harvesting susceptible stands prior to epidemics and thinning overstocked young stands to maintain vigorous trees appear to be the most desirable methods of preventing outbreaks (Sartwell 1971, Sartwell and Stevens 1975).

Bark beetle epidemics characteristically do the most damage in unmanaged or overmature stands. Like fire and wind, they provide a natural means of liquidating such stands so they can be replaced with vigorous, second-growth stands. Bark beetle problems should diminish as old-growth stands are harvested and the stocking level of the replacement stands is controlled.

The Douglas-fir tussock moth is a major defoliator of east-side mixed conifer forests, showing equal preference for Douglas-fir, grand or white fir, and subalpine fir. It also attacks other species after the preferred hosts are consumed (Wickman et al. 1973a, 1973b). Epidemic populations usually develop explosively and then subside abruptly after about 3 years. Population collapse usually results from such factors as disease organisms, insect parasites, and bird predation. Defoliation by the tussock moth can result in tree mortality, top-killing, or weakening so the trees are killed by other insects. Mortality occurs as scattered single trees throughout the outbreak area or in patches that range in size from a few to several hundred acres (Wickman 1978). Scattered tree mortality has positive as well as negative effects, since the reduction in stand density results in increased vigor and growth of the survivors and non-host trees.

Direct control is often needed to control tussock moth populations. Two microbial insecticides, *Bacillus thuringiensis* (B.t.) and a nucleopolyhedrosis virus (NPV), show promise. These agents are toxic to the tussock moth, but do not affect populations of beneficial insects, such as bees. Silvicultural control by manipulating the composition of species also seems promising. Because of the exclusion of fire and the harvesting of overstory ponderosa pine during the past 75 years, the proportion of true firs has increased greatly in many stands, and recent tussock moth outbreaks have occurred mostly in second-growth or understory stands of true fir. Maintaining pine on the more xeric sties by the use of prescribed fire could reduce the severity of further outbreaks (Williams et al. 1980). Detailed information on population dynamics and management of the tussock moth is given by Brookes et al. (1978).

The western spruce budworm is the most widespread and possibly the most destructive forest defoliator in western North America (Carolin and Honing 1972). It attacks spruce and western larch but shows a decided preference for Douglas-fir and true firs. Some epidemics subside naturally in a few years; others persist for as long as 20 years. The usual diet of the budworm larvae is the current year's foliage. Several years of defoliation can result in decreased growth, top-killing, and sometimes death of trees. In addition to feeding on foliage, the budworm severs the stem of the current year's terminal and lateral shoots of western larch and also causes damage to cones and seeds (Fellin and Schmidt 1973). Repeated severing of terminals and upper laterals produces crooked boles, deformed trees, and a considerable loss of height growth. Prompt thinning of young larch stands could reduce the incidence of budworm damage. Faster growing trees with large diameter shoots are severed less often than those with smaller shoots, and the more vigorous trees are better able to recover when budworm outbreaks subside. In the Warner Mountains of Oregon and California, sporadic outbreaks of the Modoc budworm follow a pattern similar to that of the western budworm.

The larch casebearer is the most serious pest of western larch. This defoliator, of European origin, was first discovered in the West in Idaho in 1957 (Denton 1979). Because no natural enemies were present when it was first introduced, the casebearer quickly spread throughout the range of larch and now is present in most larch stands in eastern Oregon and Washington. Typical effects of defoliation, such as growth reduction, loss of vigor, susceptibility to secondary insects, and occasional mortality, result from casebearer infestations. In addition, because of the shade intolerance of larch, this insect can seriously affect the fate of larch in mixed stands even if no mortality occurs. For larch to remain competitive in mixed stands, it must maintain a dominant position in the overstory. Repeated defoliation reduces vigor of the larch until it can no longer compete successfully with its more shade tolerant associates. Thus, even though the casebearer outbreak may subside, larch will eventually be eliminated from the stand once it loses its dominant position. The most promising means of containing the casebearer in the long run appears to be through biological control. A host-specific European parasite of the casebearer, *Agathis pumila* (Ratzeburg), was successfully introduced in western larch forests in 1960 (Denton 1972). Two other foreign parasitic wasps, *Chrysocharis laricinellae* (Ratzeburg), and *Dicladocerus westwoodii* (Westwood) were first released in 1972 and appear to be spreading (Ryan and Denton 1973). Control of the casebearer by these parasites is slow because host populations are large and widely dispersed.

The fir engraver beetle is a serious pest of true firs. It kills pole-sized to mature trees, and outbreaks often are associated with drought conditions (Ferrell 1978). Because of the sporadic nature of outbreaks and the prevalence of healthy engraver broods in living trees, direct control measures are impractical. As in the case of most beetles, the best insurance against outbreaks is to keep the trees in a vigorous, healthy condition by the proper control of stocking level and taking measures to assure stand sanitation.

The pine engraver beetle can be a serious pest of ponderosa and lodgepole pine, although outbreaks seldom last more than 1 year (Sartwell et al. 1971). Slash larger than 2 inches in diameter is generally the preferred host material for the beetle. When populations become too large for the available slash, the beetle attacks healthy living trees. Trees from 2 to 8 inches in diameter are most frequently killed, and top-killing of larger trees also occurs. The most practical way to prevent outbreaks of this beetle is by timely slash disposal and thinning of overstocked stands.

Diseases

Coniferous forests of eastern Oregon and Washington are subject to a multitude of diseases, both biotic and abiotic in nature (Hepting 1971). The most serious diseases of mixed conifer forests are trunk and root rots and dwarf mistletoes. Trunk and root rots are widespread throughout old-growth mixed conifer forests, especially in the true firs where nearly 40 percent of the volume is unmerchantable because of rot (Aho 1977). In addition to loss of volume, these rots increase the susceptibility of trees to windthrow and breakage. Aho (1971, 1977) has studied the fungi causing decay in grand fir and Engelmann spruce in the Blue Mountains and the relationship of decay to various external defect indicators, such as basal scars. Four fungi were responsible for a high proportion of infections and volume losses in grand fir. They were the Indian paint fungus, yellow pitted rot, mottled rot, and annosus root rot. By far the most damaging of these was the Indian paint fungus which alone, or associated with other fungi, accounted for 78 percent of the decay volume. Branches are apparently the major infection court for this fungus. Etheridge and Craig (1976) give a good review of the mode of infection of this fungus. The yellow pitted rot and mottled rot entered trees mainly through injuries and annosus root rot through the roots. A pathological rotation age of 125 years is suggested for grand fir.[5]

A large number of fungi were found to cause infections in spruce (Aho 1971). The three most damaging were red ring rot, red root and butt rot, and bleeding conk fungus. Aho (1966) has prepared guidelines for estimating the amount of defect in grand fir, Engelmann spruce, Douglas-fir, and western larch based on indicators such as tree age, basal injuries, and number of conks.

The laminated root rot and the shoestring root rot are also serious diseases in mixed conifer forests. The fungi which cause these diseases attack most coniferous species, but tree species vary in degree of susceptibility. Grand fir, Douglas-fir, and mountain hemlock are most susceptible to the laminated root rot (Filip and Schmitt 1979). Pines appear to suffer the most damage from the shoestring root rot. These two diseases are widespread throughout western coniferous forests, but control is expensive and should be considered only where the diseases are causing economic losses. Recommendations for control of laminated root rot are given by Hadfield and Johnson (1977) and for the shoestring root rot by Shaw and Roth (1978) and Roth and Rolph (1978). Avoiding the establishment of plantations on sites likely to have a high disease hazard, or removing the disease sources by thinning trees, uprooting stumps, and dislodging root remnants appear to be the most effective means of control.

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[5]A pathological rotation is the age at which unacceptable losses from decay occur.

Decay should be reduced in the future as overmature, old-growth mixed conifer stands are replaced by vigorous, free-growing natural or planted young stands. Evidence to support this conclusion comes from a recent study where very little decay was found in large true firs that have been free-growing most of their lives.[6]

The importance of the Indian paint fungus and other fungi in suppressed advance true fir reproduction is not fully understood at this time. Aho and Hutchins (1977) feel that a potential decay problem exists in this reproduction because of the potential reactivation of dormant infections by injuries.

Dwarf mistletoes are found on nearly every species in mixed conifer forests. Most dwarf mistletoe species are host specific; that is, they occur on only one tree species. Some may be found on three or four different species in a genus, but only rarely do they cross infect from one conifer genus to another. The biology of dwarf mistletoes has been described by Hawksworth and Wiens (1972). Mistletoe infection reduces tree growth and seed production and lowers wood quality. Eventually, the tree will die if the entire crown becomes infected. Trees respond to infection by localized swelling of branches, but considerable swelling of the main stem occurs when the parasite infects the bole directly or grows into the trunk from an infected branch. These swellings may double the normal diameter of the bole and allow decay fungi to enter the tree through cracks in the bark caused by the swellings. Trees weakened by mistletoe are also more susceptible to attack by bark beetles.

Mistletoe infection occurs on all age and size classes of trees but is most damaging in young stands in their maximum growth period. Heavy infection of the understory by the overstory can result in a stand composed of deformed and stunted trees that never attain their growth potential and are unlikely to reach rotation age. Because of host specificity, however, there is less chance of the entire understory becoming infected in mixed stands than in pure stands.

Mistletoe control in mixed stands where only one tree species is infected can be accomplished by sanitation cuttings which favor the uninfected species. In stands where several species are heavily infected, clearcutting and establishing a new stand is the best way to eliminate the parasite. It may be possible to deal with light to moderate infections in the understory through release of these trees by overstory removal and thinning. Barrett and Roth[7] have shown that because of the greater height growth after release, ponderosa pine saplings are able to outgrow the mistletoe infection with diameter growth rates equal to those of uninfected trees.

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[6]Data on file at Silviculture Laboratory, Pacific Northwest Forest and Range Experiment Station, Bend, Oregon.

[7]Barrett, James W., and Lewis F. Roth. Response of dwarf mistletoe infected pine saplings after thinning. [In preparation.]

Besides rots and dwarf mistletoe, a number of rusts cause significant damage to mixed conifer species. The most damaging is white pine blister rust. This disease is caused by a heteroecious rust fungi that requires an alternate host *(Ribes)* to complete its life cycle. It attacks nearly all soft pines but has been most destructive to eastern and western white pine; many stands have been severely damaged and some completely destroyed. Limited numbers of rust resistant western white pine seedlings are now available for reforestation as a result of genetic research conducted by the USDA Forest Service, Pacific Northwest Region's tree improvement center at Dorena, Oregon.

Bega (1978) has compiled an excellent manual for the identification of diseases of Pacific Coast conifers. It describes both biotic and abiotic diseases, and although written primarily for the Pacific Coast region, it should also be useful in the interior West. Another useful publication for identification of diseases and insects of coniferous forests has been prepared by Partridge et al. (1978).

Rodents and Birds

Rodents can cause significant mortality and damge in mixed conifer forests. Although damage can occur in areas of natural regeneration and seeded areas because of seed and seedling consumption, the most serious damage takes place in young plantations. Pocket gophers and porcupines cause most of the damage in plantations. Only minor damage is caused by other small mammals such as hares, rabbits, deer mice, and voles (Crouch 1969). In general, animal damage is more common on clearcuts than on partial cuts.

Pocket gophers can severely damage or completely destroy entire plantations, but, in general, less damage occurs in mixed conifer communities than in ponderosa and lodgepole pine communities (Volland 1974). Most of the damage is done in the winter or spring under the snowpack. Gophers commonly sever seedling roots and girdle or clip the stem. They can also burrow under the seedling and pull it partly or entirely into the ground (Barnes 1973). A variety of direct and indirect measures have been tried or proposed to control gophers. Direct measures include trapping, poisoning, flooding, fumigating, using repellents, and exclosing or caging (Crouch and Frank 1979). Indirect measures include habitat modification, such as eliminating the food supply with the use of herbicides (Crouch 1979).

Porcupines most often attack pole-size trees, but girdling of seedlings and saplings also occurs. Some trees are killed, and others suffer top damage resulting in stem deformation and loss of height growth. Porcupines have been controlled by hunting and trapping and placing strychnine-treated salt blocks in trees, high enough to prevent use by livestock and big game.

Birds do not cause significant damage in mixed conifer forests. They eat tree seed but not enough to affect natural regeneration. Birds have a more positive than negative effect, since they often help to prevent epidemics of harmful insects (Beebe 1974, Bruns 1960).

Livestock and Big Game

Damage to trees by livestock and big game is of greatest concern in young plantations. Heavy browsing of all species can occur in areas where sheep are numerous. Cattle cause seedling mortality and damage both by browsing and trampling. Most browsing of tree seedlings occurs in areas where forage is not adequate during the period of shoot growth or where cattle concentrate. Generally, browsing damage by cattle is not serious on well managed ranges. Edgerton (1971) found that browsing damage on ponderosa pine seedlings in a mixed conifer clearcut in northeastern Oregon was light when the grazing season was properly timed. An abundance of preferred herbaceous forage was available when cattle began to graze in the spring, and the animals were removed by midsummer before forage was depleted or had become unpalatable. Trampling damage increases as livestock numbers increase and is most severe in areas where cattle concentrate near water or salt blocks.

Damage to seedlings by deer and elk is generally more common than livestock damage. In a survey of animal damage in Oregon and Washington National Forests, deer were found to be causing most problems because they browse during both dormant and growing seasons (Crouch 1969). Elk also cause considerable damage in some areas by both browsing and trampling. The amount of deer and elk damage to regeneration depends upon such factors as animal populations, availability of preferred forage species, and type of seasonal range. Damage is generally most severe to ponderosa pine on lower elevation winter ranges where animals are concentrated. It is sometimes difficult to identify the animal causing the damage. A guide to identifying wildlife by the type of injury caused has been prepared by Lawrence et al. (1961).

A number of methods are available for reducing damage caused by livestock and big game. Regulated hunting in reforestation areas can reduce deer and elk to reasonable numbers (Crouch 1976), but the cooperation and approval of State Wildlife Departments is needed for such hunts. Two chemical repellents provide some protection for seedlings from browsing by deer and elk: TMTD (tetramethylthiuram disulfide) and BGR (big game repellent). The active ingredient in BGR is putrified liquid egg, and it appears to be more effective than TMTD. It only gives about 2 months of protection, however, and cannot be stored for long periods (Rochelle et al. 1974). Entire plantations can be protected from deer, elk, and cattle by fences, but the cost is very high and can usually be justified only for high value plantations such as seed orchards. Plastic tubes or wire cages may also be used to protect individual seedlings (Larson et al. 1979). Deer and elk damage to regeneration can also be reduced by increasing the size of clearcuts. Units less than 40 acres are used more heavily by deer and elk than are larger units (Thomas et al. 1979b). Finally, seedling damage can be reduced by leaving enough slash on the area to act as a physical obstruction to large animals. This has the drawback, however, of providing cover for small mammals and increases the fire hazard.

Preventing or reducing animal damage by silvicultural treatments that do not create a favorable habitat for problem animals should be considered in plant communities where problems exist. For example, partial cutting rather than clearcutting can reduce the production of forbs and grasses. Direct control may still be needed but should be easier where habitat is less than ideal and animal

populations are reduced. Control of animal damage can be difficult and expensive, especially if a number of different animals are present. A careful evaluation of which animals are causing problems is necessary before suitable methods to prevent or control damage are chosen. In many cases, the best results will be obtained by a combination of habitat modification and direct control.

Fire

Wildfire.—Fire is one of the primary natural forces in forested ecosystems and has had a major impact on vegetation patterns of mixed conifer forests. The role of wildfire in western forest ecosystems has been described by Daubenmire and Daubenmire 1968; Cooper 1961; Weaver 1961, 1974; Wellner 1970; Wagener 1961; Habeck and Mutch 1973; Heinselman 1978.

Before human activities had a significant impact on fire frequency, wildfires occurred in western mixed conifer forests at intervals ranging from 5 to 300 years. In lower elevation ponderosa pine and Douglas-fir communities, light to moderate surface fires occured at intervals of about 6 to 15 years. These light, frequent fires prevented excessive fuel accumulation, prevented true firs from invading, and thinned dense clumps of pine, thus avoiding stands stagnating from overstocking. This type of fire resulted in open, parklike stands which were typical of lower elevation communities. In contrast, the fire pattern in higher elevation communities was one of severe surface or crown fires at infrequent intervals of 100 to 300 years. These resulted in large, even-aged stands of seral species such as larch, lodgepole pine, and western white pine. These large, conflagration-type wildfires not only destroyed the standing timber but also caused soil erosion, stream sedimentation, lower water quality, and non-wettable soil. During one wildfire in the Oregon Cascades, a water repellent layer 1-9 inches thick, that formed in pumice soil on a severely burned site, persisted for 5 years (Dyrness 1976).

Fire suppression practiced during the past 60 years has had the most effect on fuels and vegetation in the lower elevation communities which had been subject to light, frequent fires.

Prescribed Fire.—Properly used, prescribed fire can be a useful silvicultural tool for managing interior mixed conifer forests. It is probably most useful in lower elevation pine and Douglas-fir communities to reestablish the natural cycle of light, frequent surface fires. The negative effects of some 60 years of fire exclusion in these communities are now readily apparent. Residues previously consumed have accumulated in large amounts, and dense, stagnated stands of advance reproduction have become established in the understory, adding to the fuel supply. In addition, ponderosa pine is gradually being replaced by the more shade-tolerant true firs in communities where pine is a seral species. The importance of restoring fire to mixed conifer communities and its potential for stand management has been recognized by Beaufait et al. 1975; Kilgore 1971, 1972; Kilgore and Briggs 1972; LeBarron 1957; Martin 1976; Norum 1977; and others.

Although the benefits of prescribed fire are now well recognized, reintroducing fire into ecosystems where it has been excluded for many years is difficult because of the large amount of fuel that has accumulated. Skillful application of prescribed burning techniques is required. Martin and Dell (1978) have developed guidelines for using prescribed burning in eastern Oregon and Washington to accomplish various management objectives. Common objectives are (1) reduce fire hazard, (2) prepare sites for natural regeneration or planting, (3) eliminate dense understories of shrubs and shade-tolerant tree species, (4) control diseases and insects, and (5) improve habitat for wildlife and livestock. In many cases, more than one objective can be attained by a single prescribed burn.

The use of prescribed fire as a silvicultural tool in the western United States is still relatively new. To develop better prescriptions, more information is needed about the response of various plant communities to fires of varying intensities, fuel consumptions, and burning conditions.

Wind and Snow

Windfall and windbreak along the boundaries of clearcuts and in partial cuttings can be a serious problem in mixed conifer stands of unmanaged old-growth. Trees in dense stands have not developed the windfirmness needed to resist wind stresses that result when the stand is opened up. Shallow-rooted species or a shallow rooting zone, such as bedrock near the surface of the soil, further compound this problem. And as noted, the presence of heart and root rots predisposes trees to wind damage. The chance of wind damage increases with greater amounts of mountain hemlock in the stand. In a survey of shelterwood units on the east-side of the Oregon Cascade Range, Seidel (1979c) found that an average of 2.4 trees per acre were blown down in a mountain hemlock/grouse huckleberry community compared with 0.5 tree per acre in a mixed conifer/snowbrush-chinkapin type.

Alexander (1964) studied wind damage in Colorado and summarized his work in guidelines for locating cutting boundaries and for identifying topographic situations where blowdown is very high, above average, or below average. Although his work is specific for spruce-fir forests in the Rocky Mountains, it probably is applicable to many high elevation mixed conifer stands in eastern Oregon and Washington.

Alexander lists topographic situations associated with three wind damage categories:

Very high—

1. Ridgetops.
2. Saddles in ridges.
3. Moderate to steep middle south- and west-facing slopes not protected to the windward.
4. All upper south- and west-facing slopes.

Above average—

1. Valley bottoms parallel to the direction of prevailing winds.
2. Gentle middle south and west slopes not protected to the windward.
3. Moderate to steep middle, and all upper north- and east-facing slopes.
4. Moderate to steep middle south- and west-facing slopes protected by considerably higher ground not far to windward.

Below average—

1. Valley bottoms, except where parallel to the direction of prevailing winds, and flat areas.
2. All lower, and gentle middle north- and east-facing slopes.
3. All lower, and gentle middle south- and west-facing slopes that are protected from the wind by considerably higher ground not far to windward.

Recommendations for locating cutting boundaries, as summarized from Alexander (1964) by Jones (1974), are:

1. Protect the vulnerable downwind boundary from wind.
2. Do not locate boundaries where uncut stands will be exposed to winds funneling through exposed saddles to the south or west.
3. When the main drainage is a narrowing valley with steep sides, avoid locating boundaries on ridgetops or near saddles, especially ridgetops or secondary drainages downwind from and at right angles to the main drainage. Such ridgetops should either be cut or left uncut for at least 200 feet down on both sides.
4. So far as other considerations permit, lay out each unit so the maximum length of cutting boundary is parallel to the contours.
5. Irregular boundaries without sharp indentations, projections, or square corners will reduce blowdown.
6. Do not locate boundaries on poorly drained or shallow soils.
7. Locate boundaries where stand conditions favor windfirmness: (a) stands of sound trees, (b) immature stands, and (c) poorly stocked stands.

The importance of leaving sound dominant and codominant trees along clearcut boundaries and in shelterwood units was pointed out by Gordon (1973a). He suggests the following types of trees be cut:

1. Intermediate or suppressed crown classes.
2. Heavy leaners.
3. Trees with decay, as indicated by conks, and those with heavy dwarf mistletoe infestations.
4. Trees with large fire scars.
5. "Twinned trees"; that is, those with a fork near ground level resulting in two trees from the same root system.

Snow movement on steep slopes can cause stem deformities and breakage of seedlings and saplings (Leaphart et al. 1972). It often causes damage to lower elevation species, such as ponderosa pine, that are planted at higher elevations where they are not normally found (Seidel 1979b).

SOME SILVICAL CHARACTERISTICS

Seed Supply

An adequate supply of sound seed is one of the essential requirements for natural regeneration; the other two are a receptive seed bed and favorable environmental conditions. Western larch, mountain hemlock, and lodgepole pine are the three most prolific seed producers in mixed conifer forests, producing some seed almost every year. Lodgepole pine cones are mostly nonserotinous in the Oregon Cascades and the Blue Mountains (USDA Forest Service 1965). In the Cascade Range of Oregon and Washington, medium to heavy cone crops generally occur at 3- to 4-year intervals (Franklin 1968, Franklin et al. 1974). Because of the variety of species in mixed conifer forests, there is a greater chance of some seed being produced every year than in stands of only a single species.

Dispersion of coniferous seed is chiefly by wind, although rodents carry away some seed and bury it. Western larch and mountain hemlock both have light seeds (average 137,000 and 114,000 seeds per pound, respectively) which are carried long distances by the wind. In Montana, enough larch seed reached the center of a square 60-acre clearcut to establish a well-stocked stand on favorable seed beds (Schmidt et al. 1976), and in the Oregon Cascades, 1 - 2 pounds of mountain hemlock seed per acre were found at the middle of a 31-acre clearcut (Franklin and Smith 1974a). Seed disperal from clearcut edges typically follows a negative exponential curve with large amounts falling within 60 - 130 feet of the boundary and a pronounced decrease in seed density at greater distances from the timber edge (fig. 3).

Dispersal of large quantities of sound seed over long distances does not guarantee natural regeneration if environmental conditions are too severe or seed beds unsuitable. Examples are the seed dispersion patterns of western larch and mountain hemlock discussed previously. Large amounts of seed of both species were dispersed over clearcuts. Because larch is a seral species well adapted to invade disturbed areas, seedling establishment was successful. On the other hand, mountain hemlock regeneration was not because it generally requires some residual overstory for successful regeneration.

Germination and Seedling Survival

The rate of germination of viable seed of coniferous species varies considerably. Laboratory tests indicate that ponderosa pine and lodgepole pine seeds generally have the highest germination rate, ranging from 60 to 70 percent, whereas the true firs have the poorest rate, less than 50 percent (USDA Forest Service 1974).

Viable seeds normally germinate following snowmelt in June, but white fir seed has germinated as early as February in northern California on patches of bare ground (Gordon 1970). Also, seeds of white fir, red fir, and subalpine fir will germinate on, in, and beneath the snowpack (Gordon 1970, Franklin and Krueger 1968). Many potential seedlings die when the snow melts because the radicle dries out before it can penetrate the soil. Consequently, the weather conditions in the fall can have a significant effect on seedling establishment the following spring. Seeds that fall before a permanent snowpack develops have a much better chance of producing established seedlings than those that fall on the snowpack.

The first growing season after germination is the most critical period for young seedlings; most of the mortality occurs during this time, although losses may be considerable during the first 5 years. The ability of seedlings to survive depends upon their tolerance of the stresses imposed by five primary variables: light, temperature, moisture, chemical factors, and physical factors. These primary variables are affected, in turn, by the many secondary variables, such as seed bed condition, understory vegetation, aspect, and slope.

Mineral soil is the most favorable seed bed for all coniferous species because it is a more stable source of moisture and is cooler than litter and duff layers (Seidel and Cooley 1974). Larch and lodgepole pine require exposed mineral soil for successful establishment. True firs also become established better on mineral soil, but they also survive in light litter and duff layers up to about ½-inch thick (Seidel 1979a).

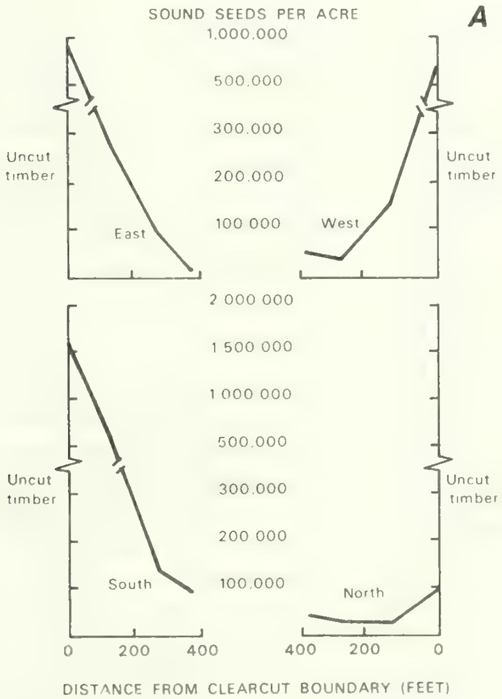
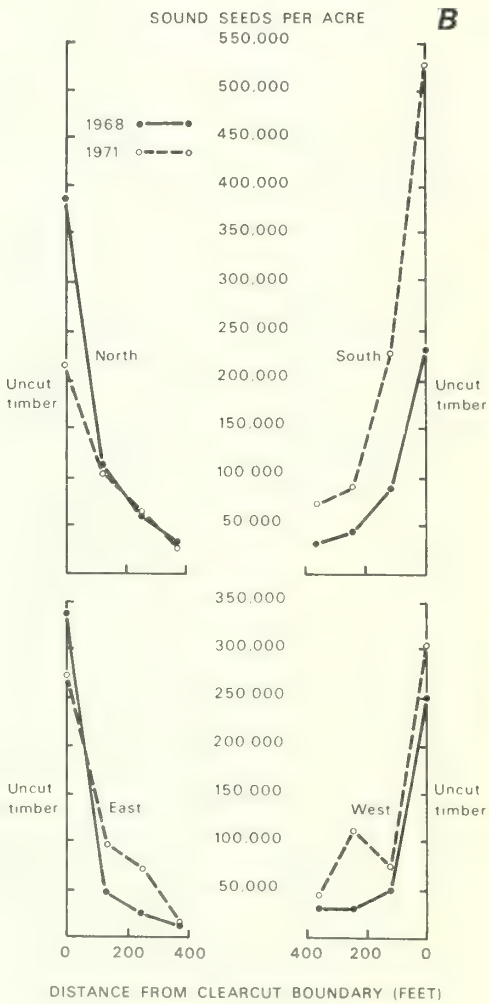


Figure 3.—Seedfall into clearcuts as related to distance from stand edge: *A*, mountain hemlock, 1968 cone crop; (Reproduced from Franklin and Smith 1974a, fig. 2); *B*, white and Shasta red fir, 1968 and 1971 cone crops; (Reproduced from Franklin and Smith 1974b, fig. 2.)



On the east slopes of the Oregon Cascades, inadequate soil moisture is not generally a problem—providing competition from understory vegetation is not severe. In several studies of true fir regeneration in central Oregon, Seidel and Cooley (1974) found that soil moisture was always well above the "wilting point," and seedling moisture stress (xylem pressure potential) was never less than −15 bars throughout the summer. Fowells and Stark (1965) also reported that even during a 4-month drought, soil moisture was nearly always available to seedlings in the mixed conifer type of northern California. Seedlings avoid drought by rapid root growth so that root tips always stay ahead of the drying front in the soil. Root growth of true fir during the first growing season in central Oregon exceeds 6 inches and in northern California ranges from 6 to 12 inches (Gordon 1970).

Extremes in temperature cause considerable seedling mortality. Temperatures as high as 163°F can be reached at the soil surface (Seidel and Cooley 1974). Higher temperatures are reached on organic seed beds than on mineral soil. Injury to seedlings by direct freezing is most likely to occur in spring when they are still succulent, whereas damage from frost heaving occurs in fall when daytime temperatures are warm, temperatures at night are freezing, and soils are saturated with moisture. It is not extremes of temperature alone that result in seedling mortality but also the length of time seedlings are exposed to them. A series of "isosurvival curves" for grand fir seedlings were constructed for a central Oregon seed source (Seidel 1974a). The curves indicate the combinations of time-freezing temperature that result in equal survival. Extremes in temperature can be mitigated by partial shade from an overstory and/or by light amounts of slash which reduces radiation cooling and decreases solar insolation.

Seedling survival is reduced in severely burned areas because of decreased water infiltration into the soil and higher temperatures of the charcoal surface. In a study of regeneration in mixed conifer clearcuts in eastern Oregon, Seidel (1979b) found the pile-and-burn treatment was a strong negative factor in seedling establishment, in contrast to broadcast burning which had a small positive effect. Vogl and Ryder (1969) also attributed poor regeneration in a Montana study to conditions created by severe fire. Although seedling establishment may be reduced where piles of slash have been burned, the impact of this treatment on regeneration is small because slash piles generally occupy only a small part of the total reforestation area.

The amount of understory vegetation, especially grasses and sedges, has a strong influence on the success of natural regeneration. On eastern Oregon clearcuts and in the Cascade Range and the Blue Mountains, the presence of grasses and sedges was negatively correlated with seedling establishment (Seidel 1979b). After an area has been disturbed by logging and site preparation, the amount of tree regeneration depends to a large extent on how fast understory vegetation reinvades. Seed beds in shelterwood units in mixed conifer/snowbrush-chinkapin and mountain hemlock/grouse huckleberry communities of the eastern Oregon Cascades have remained receptive to seed for at least 5 years after a seed cut (Seidel 1979c).

To summarize, it appears that seed germination and seedling survival is enhanced by a mineral soil seed bed that has not been severely burned, by the absence of competing understory vegetation, and, for the more tolerant species, by light shade cast by slash or overstory. More detailed information on silvics of mixed conifer species can be found in "Silvics of forest trees of the United States" (USDA Forest Service 1965). Comparative autecological information for Northwestern tree species is given by Minore (1979).

SILVICULTURE AND MANAGEMENT

Silviculture is an attempt to manage forests by influencing ecological processes to attain specified objectives. Given sufficient time, nature will replace most forests in temperate climates following disturbances such as logging or fire, but the result may not be satisfactory to humans in terms of species composition or stand structure. Therefore, the basic justification for silvicultural manipulation of forests is an economic one—to speed up the regeneration process by planting or direct seeding, for example, or to shorten the rotation by controlling stocking level.

The primary objective of silvicultural prescriptions is timber management, and that will receive the major emphasis in the following discussions. Other multiple-use resources of the forest, such as water yields, wildlife, forage, and recreation, are also affected by silvicultural treatments. In many cases, one or more of these resources are compatible with timber goals such as the increase in water and forage yields associated with stocking level control.

Regeneration Systems

Because of the large number of species and stand conditions in mixed conifer forests of eastern Oregon and Washington, both even-aged and uneven-aged silvicultural systems can be used for their management. The complex nature of old-growth stands can result in considerable variation from acre to acre and may require a compromise between what is desirable and what is possible. On the other hand, the range of silvicultural systems available to the land manager enables him or her to better integrate silvicultural prescriptions with other resources.

Franklin and DeBell (1973) surveyed the effects of cutting methods on regeneration and concluded:

> Few situations require either extreme in treatment—uneven-age management using a selection system or even-aged management using large clearcuttings. On the other hand, either of these extremes could be applied much more widely to regenerate forests successfully if a type or species conversion is acceptable, as in the selection system, or a dependable technique for artificial regeneration is available, as in extensive clearcutting. On the majority of productive forest sites, factors other than ecological limitations of the species appear to be primary in the choice between uneven- and even-age management and among the several silvicultural systems that can be used to create even-age stands. These include: economic considerations, including efficiency in logging, growth rates, and costs and returns on investments; social considerations, such as the esthetics of cutover areas and effect on other resource values—soil, water quality, and wildlife habitat; physical considerations such as the terrain with its limitations on suitable logging methods; and other biological considerations such as presence or absence of damaging agents—dwarf mistletoe, large deer population, and some insects or fungi.

Even-Aged Management.—In mixed conifer stands where timber production is an important objective, the use of silvicultural systems which result in even-aged stands is recommended (Seidel 1973). Even-aged management is desirable to convert overmature, old-growth stands to vigorous, fast-growing, second-growth stands and to secure regeneration of the shade intolerant species. It also has an economic advantage as markets for smaller material increase and the removal of large volumes reduces logging costs by spreading fixed costs over a greater volume removed.

Clearcutting method.—The term "clearcutting" in the discussion that follows is used in the literal sense of the word; that is, removing essentially all trees from an area, followed by establishment of a new stand by either natural or artificial regeneration. Cuttings where all the overstory is removed leaving varying amounts of advance reproduction are the final cuts in the shelterwood system. Discussion of that system begins on p. 30.

Clearcutting has several advantages as a harvesting method in old-growth mixed conifer stands. It is the best way of quickly removing all trees in areas where heavy infestations of dwarf mistletoe exist in both overstory and understory or where heart rots are prevalent in the overstory. Since lateral movement of mistletoe is very slow (about one-half foot per year) from infected trees at the clearcut edge, the new stand will remain uninfected for long periods. Clearcutting allows regeneration to develop without suppression or possible damage from a residual overstory and eliminates the risk of blowdown in areas where probability of wind damage is high. It is well-suited for regeneration of seral species such as larch and lodgepole pine.

On the other hand, there are also disadvantages. Removing all trees on steep slopes can result in mass soil movement because reduced transpiration drain increases soil water content. Understory vegetation also develops rapidly on many clearcuts, requiring measures to reduce competition to tree regeneration. And animal damage to reproduction is often greater on clearcuts than in partial cuts.

Esthetic considerations are increasingly important in planning clearcuts as recreational use of forests rises. Clearcuts should be blended into the landscape by modifying boundaries and adjusting sizes to follow natural topographic and vegetative features.

A. Natural regeneration

Mixed conifer clearcuts can be adequately regenerated with natural reproduction if sufficient seed falls on receptive seed beds and microclimatic conditions are favorable for germination and survival. Clearcuts must be designed so seed can reach all parts. In a survey of clearcuts in the Oregon Cascades and Blue Mountains, Seidel (1979b) found that stocking was not affected within about 530 feet from the clearcut edge. In white fir-red fir stands in northern California, natural regeneration was better on 130- to 200-foot-wide clearcut strips than on those 333 feet wide (Gordon 1970). And

in the intermountain region, seeding was effective from 265 to 660 feet from clearcut edges, depending upon the aspect (Roe et al. 1970). As might be expected, natural regeneration is better on strip and patch clearcuts than on larger, "staggered-setting" clearcuts of 40 acres or more (Franklin 1963). The probability of obtaining adequate natural regeneration in clearcuts is greatest on north and east aspects, and, because of the prevailing southwesterly winds, strips oriented in a NW-SE direction provide the best seed distribution and least chance of wind damage.

Although natural regeneration can effectively reforest mixed conifer clearcuts, there is no assurance it will occur quickly. If the seed bed is occupied by grasses and shrubs before a heavy seed year, the chance of tree seedlings becoming established is small. Grass competes heavily with tree seedlings for soil moisture. In the Oregon Cascade and Blue Mountain clearcuts, grass was negatively correlated with seedling establishment (Seidel 1979b). Shade-tolerant seedlings did become established under snowbrush and manzanita, but growth was slow. Therefore, because of the chance of losing the seed bed to grass and/or shrubs within a few years after clearcutting, natural regeneration seems best suited as a supplemental rather than primary method of reforesting mixed conifer clearcuts. Natural regeneration has the best chance of success on north and east aspects, at distances up to about 333 feet from a seed source, and where the stand at the clearcut edge contains larch and/or lodgepole pine seed trees.

B. Direct seeding

There have been no studies of direct seeding (broadcast or spot seeding) in mixed conifer forests of eastern Oregon and Washington. In general, however, direct seeding trials in the West have not been successful because of problems with seed predators, poor seed beds, or unfavorable environments. In a test in the western Cascades, stocking of seed spots was not satisfactory without protection by wire screens, even when repellent-treated seed was used on areas baited to control rodents (Franklin and Hoffman 1968). Of the mixed conifer species, western larch is one of the best adapted to direct seeding because its small seeds are not as subject to rodent depredation as are larger seeds (Shearer and Halvorson 1967). Because of these limitations, direct seeding is not recommended as a primary means of artificial regeneration but seems best suited for use (1) when suitable planting stock is not available to reforest large areas (e.g., after a large wildfire), (2) on rocky sites where planting is difficult, or (3) on sites where access is limited during the planting season. Even these uses of direct seeding are decreasing, however, because container-grown seedlings are used to supply planting stock for emergencies and to lengthen the planting season on high elevation sites.

C. Planting

All mixed conifer clearcuts should be planted, except where local experience shows that natural regeneration is sufficiently reliable to reforest the area in an acceptable period. Planting should be done immediately after logging and slash disposal operations are completed to establish a vigorous, fast-growing stand of trees before competing vegetation occupies the site. Seedlings planted on clearcuts are not subject to suppression from a residual overstory or to damage and mortality when the overstory is removed, as are seedlings planted in shelterwood units. Planting also offers the opportunity to control spacing and species composition, and size of clearcuts is not limited as with natural regeneration.

Establishing plantations is a complex and expensive operation. It involves many steps. These include obtaining correct seed source; producing vigorous nursery stock; proper lifting, handling, and storage of stock; careful planting; and controlling animal damage. Plantation failure can result if any one of these steps is not done correctly. Details of all the steps necessary for successful plantation establishment have been prepared by Cleary et al. (1978) and by Ronco (1972). The rest of this section summarizes some important factors.

1. Site preparation. Site preparation is a means of temporarily eliminating competing vegetation, thereby giving planted or natural tree regeneraiton a more favorable environment for establishment and growth. Site preparation can be accomplished by mechanical or chemical methods, or by using fire. Often a combination of these methods is more effective than a single method. Stewart (1978) has prepared an excellent review of the uses and limitations of various site preparation methods in Oregon. He describes methods suitable for harvested areas or burns, for poorly stocked existing plantations, and for brushfields.

The choice of a site preparation method in a given area depends upon seven factors: (1) the nature of existing ground cover, (2) physical site factors, (3) site preparation requirements, (4) available personnel and equipment, (5) external constraints, (6) environmental impacts, and (7) cost.

Sites occupied by dense, well-established stands of shrubs require more complete site preparation than those with only herbaceous plants. Physical factors such as slope, aspect, soil type, erosion potential, and access will influence the choice of site preparation method.

Site preparation required will depend on the vegetation succession expected after disturbance, regeneration methods and species available, and the severity of the environment in relation to the tree species chosen (Pfister 1973). For example, prescribed burning in a Douglas-fir/pinegrass plant community in eastern Washington will result in profuse development of grasses. Therefore, scarification or herbicides is preferred to eliminate root systems of these graminoid species. As knowledge of successional trends in plant communities increases, the silviculturist can choose site preparation methods that minimize establishment of unwanted species.

Species and size of planting stock should be matched to site preparation method. For example, shade tolerant species or large seedlings may reduce the degree of site preparation needed (Newton 1973). Therefore, reforestation plans should specify combinations of species and size classes that require minimum site preparation and investment.

Regardless of method, site preparation is expensive. If clearcuts are reforested immediately after harvest and slash disposal operations are completed, site preparation may not be necessary and these costs can be avoided. Finally, the land manager should be aware that reinvasion of planted clearcuts by shrubs may require one or more chemical or mechanical treatments to release the trees.

2. Species selection. It is important to select species that are native to the plant community. Planting off-site species can result in excessive mortality and damage from snow or ice. For example, on east-side Cascade clearcuts, ponderosa pine was planted on lower elevation clearcuts and some high elevation, mountain hemlock clearcuts. As a result — even though all areas had been planted at the same spacing (8 by 8 feet) — survival was decreased significantly at the higher elevations (fig. 4) (Seidel 1979b). In addition to greater mortality associated with higher elevation, there was a noticeable increase in the amount of snow damage (stem deformation and breakage) to the pine.

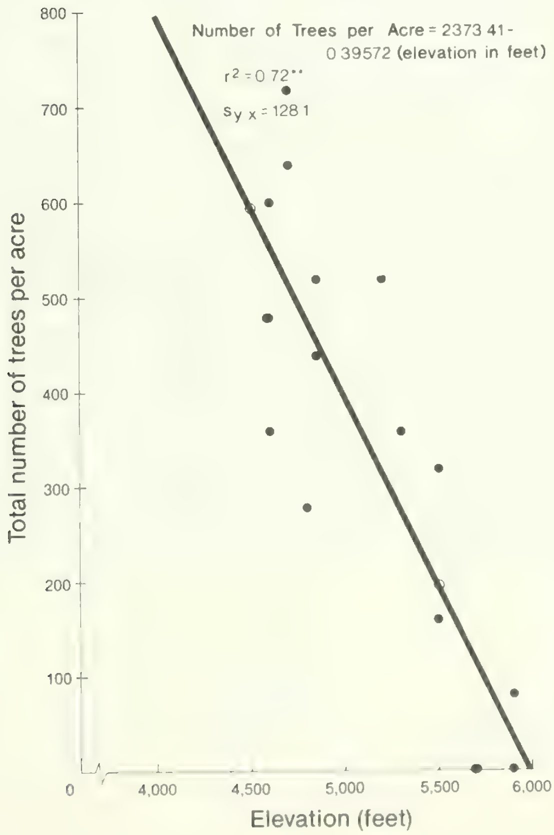


Figure 4.—On clearcuts in the eastern Cascade Range, the number of planted ponderosa pine decreased as elevation increased. (Adapted from Seidel 1979b.)

Ponderosa pine and Douglas-fir are good choices in clearcuts below about 5,300 feet. Douglas-fir should be considered for north and east slopes whereas ponderosa pine should be favored on warmer south and west aspects. In most of the clearcuts in the mixed conifer/snowbrush-chinkapin community in the Cascades, planted ponderosa pine becomes dominant because of its rapid growth (Seidel 1979b). In higher elevation clearcuts, lodgepole pine survives and grows well in mountain hemlock communities; in the Blue Mountains, lodgepole pine, larch, and Engelmann spruce are desirable species. Rust-resistant white pine is also suitable for mountain hemlock communities. The more shade tolerant spruce should be planted on north and east slopes. True firs (grand and Shasta red fir) have been planted on some mixed conifer clearcuts, but, in general, survival has not been as good as for the more seral species. Planting a number of species in mixed conifer clearcuts is recommended. This enables the silviculturist to match the species to site conditions it can best tolerate. In addition, establishing more than one species reduces the chance of losing the entire plantation to insects or diseases.

3. Planting stock. Both bare-root and container-grown planting stock are available. Each type has advantages and disadvantages. Some advantages of container-grown stock are: (1) faster production and more flexible growing schedules, (2) higher quality of some species, such as hemlock and true firs, (3) transplant shock is reduced because root systems are disturbed less, (4) extension of planting seasons, (5) easier planting in rocky soil, and (6) more adapatable to mechanization in nursery and field. Some disadvantages are: (1) higher production and transportation costs, (2) potting mix is subject to rapid moisture and nutrient losses, (3) smaller seedlings are more likely to be buried, overtopped by competing vegetation, or damaged by animals, and (4) greater potential for root binding or spiraling resulting in poor anchoring in the soil. In general, initial field performance of container-grown seedlings in the Pacific Northwest has been poorer than that of bare-root stock (Gutzwiler and Winjum 1974). Performance is quite variable, however, depending on species, site, and size of seedlings. Initial survival of ponderosa and lodgepole pine container-grown seedlings was lower than bare-root stock because of heavier animal damage on the smaller, less woody container-grown seedlings. It appears that the primary reliance should be on bare-root seedlings, with container-grown stock being used for special situations such as on rocky sites, or when true firs and hemlock are planted. In situations where field performance is about equal, the choice of stock will probably depend on relative costs, availability at specific times, speed and ease of planting, and type of planting equipment available.

Only healthy, vigorous planting stock should be used. Larger seedlings have an advantage on severe sites where vegetative competition, soil movement, frost heaving, or animal damage are problems. Size of seedlings will depend to a large extent on the inherent growth patterns of the species, but bare-root seedlings should have tops at least 4-5 inches long. Roots should not be shorter than 5-6 inches and should be compact, fibrous, and have several well developed lateral roots. The proper balance between shoot and root systems (shoot-root ratio) is more important than size of either shoots or roots. Survival of Douglas-fir planted in the eastern Washington Cascades was greater as the shoot-root ratio decreased (Lopushinsky and Beebe 1976). Shoot-root ratios in the 2.0 to 3.0 range (by weight) are considered acceptable, with ratios closer to 2.0 being the most desirable.

Selecting suitable planting stock on the basis of seedling age (1-0, 2-0, 1-1, 2-1) is not recommended because this system is too variable to accurately describe seedling characteristics. Seedling size depends upon environmental conditions and nursery practices, and therefore age alone cannot describe size of tops, roots, or the shoot-root ratio.

4. Storage. Seedlings should be lifted when dormant and stored so that seedling temperature is about 35°F. Storage up to 3 months is possible at this temperature. During shipment to the field, seedlings must be maintained at temperatures under 39°F with either refrigerated units or ice. Seedling storage in the field is more difficult because limited facilities make it hard to control temperature. Well insulated sheds cooled by ice or snow are suitable, and at high elevation sites, a pit or culvert snow cache will provide good storage (Dahlgreen et al. 1974). Field storage generally should not exceed 7 days.

5. Planting seasons. Spring planting immediately after snowmelt generally results in better survival than fall planting because soil moisture is at a maximum and new root growth quickly supplies water lost by transpiration. A study in northern Idaho showed that 1st-year survival of spring-planted Douglas-fir, Engelmann spruce, grand fir, and western larch seedlings was generally better than survival of fall plantings (Sinclair and Boyd 1973).

Fall planting may be necessary on high elevation sites, however, because the time between snowmelt in spring and the onset of very hot, dry weather may not be sufficient to complete the job. Fall planting is most likely to succeed if the ground is quickly covered by snow, since this protects seedlings from frost heaving and desiccating winds.

Planting should be temporarily suspended when high temperatures or wind velocities cause excessive water loss from seedlings. As a general rule, air temperature should be between 32° and 64°F and wind speed should be less than 20 miles per hour for planting seedlings without undue risk (Cleary 1971).

6. Spacing. The spacing interval selected for plantations depends upon a number of factors; the expected survival rate, future thinnings, and product objectives are the most important. Narrow spacings are indicated if low survival rates are anticipated, thinning is planned, and a market for small material is available or expected. On the other hand, wide spacings are suggested if anticipated survival is high, no thinnings are planned, and only a sawlog market exists. The species planted can also influence spacing. Wider spacing is indicated for faster-growing species. A reasonable range of spacings for mixed conifer stands ranges from 8 by 8 feet, 680 trees per acre, to 12 by 12 feet, 302 trees per acre. It is not necessary to maintain rigid spacing. Planting spots should take advantage of shade cast by stumps, logs, or slash where possible, especially when planting species such as the true firs or Engelmann spruce. Avoid planting in spots where skidding or slash disposal operations have buried organic matter in the soil and in areas with an extensive cover of sod-forming grasses.

7. Plantation protection. Planted seedlings must be protected from livestock, big game, and small mammals. Trampling by livestock can cause considerable damage, and fencing or adjustments in grazing allotments may be needed for several years. Control of pocket gophers and other small mammals should be undertaken when needed, following the guidelines given in the animal damage control handbook.[8]

Shelterwood method. —Use of the shelterwood method in mixed conifer forests of eastern Oregon and Washington has increased considerably during the past 15 years. There are advantages and disadvantages to using this regeneration method, as in all cutting methods, and these must be weighed in deciding what cutting method is suitable for a given area. The shelterwood method is well suited for moderating high and low temperatures or intense sunlight and thus enhances natural regeneration of more shade-tolerant species such as true fir (McDonald 1976a, 1976b). It slows the invasion of understory vegetation, leaving seed beds more receptive to tree seedling establishment, and it reduces competition. It reduces the chance of soil movement on steep slopes and decreases the probability of animal damage to regeneration. Perhaps the major reason why use of the shelterwood method has increased in high elevation mixed conifer forests is an esthetic one—harvested units look better.

The chief disadvantage of the shelterwood method in old-growth forests is the chance of losing the residual overstory by windthrow. This drawback will diminish as more second-growth stands are managed and trees become more windfirm. Other disadvantages are possible infection of the regeneration with dwarf mistletoe, and damage or loss to reproduction when the overstory is removed.

[8]USDA Forest Service Handbook 2609.22. Pacific Northwest Region, Portland, Oreg.

A. With advance reproduction

Many mixed conifer stands have a two-storied structure consisting of an overstory of larch or lodgepole pine and an understory of true fir. In this type of stand, the manager must decide if he or she wishes to manage the advance reproduction or destroy it and start over with natural regeneration. If the first alternative is selected, the reproduction method amounts essentially to the removal cuts of the shelterwood system.

To make this decision, it is necessary to evaluate the amount and condition of the advance reproduction. By today's standards, 400-500 well-distributed trees per acre appear to be sufficient after logging and slash disposal operations are completed.[9]

Based on the assumption that about one-half of the advance reproduction will be destroyed during the removal cuts, the understory should contain at least 800-1,000 trees per acre before logging. To be acceptable, advance reproduction must be of good form and have few injuries. Trees must be vigorous and have the potential for rapid growth when released (fig. 5). After

Figure 5.—A vigorous, full-crowned grand fir sapling that grew rapidly after the overstory was removed. Ochoco National Forest, Oregon.

[9]USDA Forest Service Handbook 2409.26d, Silvicultural Examination and Prescription. Pacific Northwest Region, Portland, Oreg.

release, the growth response of suppressed advance reproduction is primarily a function of tree vigor—age is relatively unimportant. Suppressed seedlings and saplings will respond up to 80 years of age. In some cases growth response occurs immediately after release, and in others it is delayed for several years. In a study in the central Oregon Cascades, both diameter and height growth of suppressed 43-year-old grand fir and Shasta red fir advance reproduction increased two to three times above the pre-release rate after the lodgepole pine overstory was eliminated (Seidel 1977b). Most of these trees were fully crowned with more than 50 percent live crown. In northern Idaho, annual height growth of suppressed grand fir saplings following release by removing the overstory was two to three times greater than the growth rate before release, and increased growth began 2 years after release (Ferguson and Adams 1979). And in northern California, height growth of released suppressed white fir and red fir seedlings and saplings increased from about 0.1 foot per year to 0.6 foot per year; radial growth rate increased from 70-100 rings per inch to 7-12 rings (Gordon 1973b). In this study, diameter growth response occurred within 1-2 years after release, but increased height growth was not evident until the 5th year after release. These results suggest that a reasonable growth response cannot be expected unless the understory trees have a live crown covering at least 50 percent of the tree. Height growth after release is also related to height growth before release. In a study of suppressed grand fir in central Oregon, trees growing slowly before release usually grew slowly after release, and faster growing trees continued to grow at a faster rate (Seidel 1980a).

In addition to anticipated growth response of the advance reproduction after overstory removal, consideration should be given to the possibility that heart rots may cause future volume losses. The question of heart rotting fungi in true fir advance reproduction being reactivated by wounds has not been completely resolved. Recent work by Filip and Aho (1978) in the Fremont National Forest, Oregon, suggests, however, that under certain conditions a high risk exists that serious decay will develop in advance white fir regeneration. They concluded these conditions indicate high risk:

1. Overstory of white fir infected with Indian paint fungus.
2. Advance white fir regeneration that has been suppressed for over 50 years.
3. Advance white fir regeneration that has numerous wounds.
4. Advance white fire regeneration of low vigor because it is growing on a poor site.

If three or more of these conditions are present in a stand, the advance white fir regeneration has a high potential for developing serious decay. Advance reproduction of other species should be favored in such stands or the regeneration destroyed and new seedlings established.

When making decisions regarding advance true fir reproduction, it is important to consider both potential growth, as indicated by tree vigor, and the potential for decay. For example, on good sites the rapid growth of vigorous fir reproduction may compensate for loss by decay. If the decision is made to manage the advance reproduction, damage to the regeneration

should be reduced as much as possible by careful logging practices (Gravelle 1977). If stocking permits, scarred trees should be removed in the first thinning.

If the advance reproduction consists chiefly of seedlings and saplings, the overstory may be removed in a single sale involving two- or three-stage logging. If the understory contains many pole-sized trees larger than 4 inches in diameter, consideration should be given to removing the overstory in several sales, provided windfall hazard is average. Removing about one-third of the overstory in each of three cuts at 5- to 10-year intervals should permit the pole-sized trees to develop windfirmness and prevent serious blowdown of the residual overstory.

After the final removal cut, areas should be evaluated for adequacy of stocking, and understocked holes about three-fourths of an acre or larger should be promptly planted with species native to the site. Landings to be retained for future silvicultural treatments or for wildlife openings should be seeded with forage species and others planted to trees.

When making overstory removal cuts, it is essential that the operator understand the need for saving the advance saplings and poles at each entry and make a conscientious effort to do so. This requires good communication between the sale administrator and the operator and close supervision by the administrator (see the discussion on logging considerations, page 39).

Another factor that should be considered when evaluating advance reproduction is a comparison of its height growth potential with that of seedlings planted in a clearcut. A potential height advantage for planted trees at some time in the future would be an indication that clearcutting and planting might be desirable, whereas greater height of the advance reproduction would suggest managing the existing regeneration.

To make such an evaluation, it is necessary to know the average height of planted seedlings and the advance reproduction and the average height growth rates of both. The manager can estimate from the following equation the annual growth rate required of planted seedlings to equal the height of the advance reproduction at the end of a given period. (Seidel 1980b):

$$A = \frac{B - E}{D} + C;$$

where

A = annual height growth of planted seedlings needed to equal height of advance reproduction at the end of a given period,
B = average height of advance reproduction after overstory removal,
C = average annual height growth of advance reproduction after release,
D = number of years in growth period, and
E = average height of planted seedlings.

B. Without advance reproduction

Use of the shelterwood method in old-growth mixed conifer stands where advance reproduction is lacking or where it is not of acceptable quality requires a residual overstory sufficient to provide seed and shelter over the entire area and a receptive seed bed. In addition, the risk of losing the overstory by windthrow must be considered.

In a survey of shelterwood units in the eastern Cascades, blowdown of the residual overstory was not severe—6 percent of the trees left after the seed cut were windthrown in a mixed conifer community, compared to a 16 percent loss in a mountain hemlock community (Seidel 1979c). Mountain hemlock is especially susceptible to blowdown because of its shallow root system, and extensive loss of this species can occur along clearcut edges and in shelterwood units (fig. 6). It should be discriminated against when marking seed cuts. This practice not only reduces the chance of blowdown but increases the chance of successful regeneration by providing more seed of species, such as the true firs, that regenerate better than mountain hemlock at lower stand densities. In situtations where risk of wind damage is very high, even light cuts may result in unacceptable blowdown. In these situations, the shelterwood method is not a suitable regeneration technique; the choice is limited to clearcutting and planting or no treatment.

Natural regeneration after seed cuts in both mixed conifer and mountain hemlock communities in the eastern Oregon Cascades has generally been good to excellent (Seidel 1979c). An average of 63 percent of milacre quadrats were stocked in both plant communities. Seedling density averaged 4,483 per acre in the mountain hemlock type and 2,968 in the mixed conifer. Over 90 percent of the seedlings in both types were of natural origin (fig. 7). And in the Blue Mountains, natural regeneration was also prolific following the seed cut in a mixed conifer community.[10] In general, shelterwood cutting is most useful for obtaining natural regeneration on south and west aspects.

The residual overstory after the seed cut should be only enough to provide adequate natural regeneration because damage to the reproduction during overstory removal and slash disposal is more likely as overstory density increases. A residual overstory of 60-80 square feet of basal area per acre is sufficient for adequate natural regeneration in both mixed conifer and mountain hemlock communities in the eastern Oregon Cascades, with the exception of pure mountain hemlock stands (Seidel 1979c). Natural regeneration of pure mountain hemlock apparently requires densities greater than 100 square feet of basal area per acre, but more research is needed on this species (Seidel and Cooley 1974).

[10]Data on file at Silviculture Laboratory, Pacific Northwest Forest and Range Experiment Station, Bend, Oregon.

Figure 6.—Blowdown of mountain hemlock after shelterwood cutting. Deschutes National Forest, Oregon.

Figure 7.—Five-year-old grand fir seedlings in shelterwood unit. Deschutes National Forest, Oregon.

Figure 8.—Shelterwood unit after the seed cut in a grand fir-Shasta red fir stand. Leave trees were marked. Deschutes National Forest, Oregon.

When marking a stand for a seed cut, it is important to mark the leave trees rather than the cut trees. Marking the leave trees focuses the marker's attention on the best trees in the stand. In addition, marking leave trees reduces the tendency to leave too dense an overstory which can occur if the cut trees are marked. Leave trees should be uniformly distributed over the unit. Leave trees should be dominants or codominants with long, full symmetrical crowns and free from insect or disease infestation (fig. 8). Such trees are the best seed producers and the most windfirm. In some mixed conifer stands, the best overstory trees have been cut (high-graded) leaving only poorer quality intermediates or codominants. The shelterwood system should not be used in this type of stand.

Figure 9.—Shelterwood unit 7 years after the seed cut in a mountain hemlock-grand fir stand. Note the absence of understory vegetation. Deschutes National Forest, Oregon.

The greatest chance of securing natural regeneration with the shelterwood method occurs when the seed cut coincides with a bumper seed crop. Natural regeneration typically occurs in "waves" which result from heavy seed fall on receptive seed beds. Although seed cuts made in heavy seed years provide ideal conditions for natural regeneration, adequate stocking can be obtained from several years of light to medium seed fall , provided the seed bed remains receptive. Several studies in the eastern Oregon Cascades have shown that the residual overstory tends to inhibit the invasion of competing understory vegetation for at least 5 years (Seidel 1979a, 1979c) (fig. 9). Williamson (1973) also reported satisfactory natural regeneration of Douglas-fir after several years of low seed fall. Therefore, it appears that although a heavy seed year immediately after the seed cut provides optimum conditions for establishment of natural regeneration, it is not essential to schedule seed cuts to coincide with heavy seed years.

As discussed previously, a mineral soil seed bed is the most favorable for seedling establishment. Seed per seedling ratios indicated the superiority of a mineral soil seed bed in a study of true fir natural regeneration after shelterwood cutting in the central Oregon Cascades (Seidel 1979a). Fewer sound seeds were needed to produce one seedling on plots where mineral soil was exposed (table 2). Although seedling establishment is better on mineral soil, complete removal of litter and duff layers is not necessary nor is it desirable. Exposure of only about 40-50 percent of the mineral soil is needed. This will result from logging and slash disposal operations.

Table 2—Sound seed per seedling ratio for grand fir and Shasta red fir by slash treatment and overstory density, based on 1974 seed year and 1975 seedling count[1]

Slash treatment	Overstory density		
	50 square feet per acre	90 square feet per acre	130 square feet per acre
		Grand fir	
None	38:1	63:1	43:1
Lop and scatter	49:1	55:1	43:1
Bulldoze	21:1	22:1	31:1
Crush	37:1	63:1	34:1
		Red fir	
None	6:1	16:1	7:1
Lop and scatter	6:1	11:1	8:1
Bulldoze	3:1	4:1	2:1
Crush	4:1	9:1	10:1

[1]Adapted from table 2, Seidel (1979a).

The shelterwood system is ideally suited for obtaining natural regeneration because it provides good distribution of seed over the area, ameliorates environmental extremes, and inhibits competing understory vegetation. For these reasons, natural regeneration should be relied on when using the shelterwood system. Planting should be only a means to raise stocking above minimum standards. The most efficient use of planting in the shelterwood system is to increase stocking if it is below minimum standards **after** removing the residual overstory. Planted seedlings are then not subject to loss or damage by logging operations as they are when planted before the overstory is removed.

Generally in east-side mixed conifer forests, planted seedlings do not need the protection of a shelterwood. Therefore, if local experience shows that shelterwood units do not regenerate naturally in an acceptable period, units should be clearcut and planted. An exception should be made in frost pockets where planted seedlings will not survive or grow without the thermal protection of some overstory. If natural regeneration does not occur in these areas, planting should be done before the overstory is removed.

Uneven-Aged Management.—As discussed previously, the choice of even-aged or uneven-aged management in the mixed conifer forests of eastern Oregon and Washington generally depends on factors other than ecology or silvical characteristics of the species. Under intensive forest management, even-aged systems are preferred to remove large volumes of defective trees, to maintain desired species in the stand, and for economic reasons. Uneven-aged management appears to be most suitable in areas of high recreational value — near campgrounds, for example — or where establishment of shade-tolerant species

makes maintaining a single-storied, even-aged stand difficult and expensive. An example of this condition occurs in northeastern Washington where abundant natural regeneration of western hemlock and western red cedar can frustrate efforts to control the stocking level of even-aged stands.

Another use of uneven-aged management is in pure mountain hemlock stands where natural regeneration may be enhanced by the group-selection method. In the Cascades, natural regeneration of mountain hemlock characteristically occurs in small openings where several trees have fallen. Simulating this condition by harvesting groups of trees covering about one-fourth acre may result in an environment favorable for mountain hemlock regeneration. It should be recognized that although natural regeneration is favored by the group-selection method, growth of the regeneration may be suppressed by the mature trees surrounding these small openings. Because their roots extend into the openings, the surrounding trees can complete with seedlings for distances of 50-60 feet.[11] Thus growth of reproduction could be retarded over much of any opening less than an acre in size. Openings larger than 1 acre may not qualify as uneven-aged management.

A true single-tree selection method has never been applied to any mixed conifer community in eastern Oregon or Washington and probably has never been used in any Western forest type. To successfully regulate uneven-aged management using a single-tree selection system, three interrelated factors must be considered (Alexander and Edminster 1977a): (1) a maximum tree size goal, (2) stocking level (the residual growing stock that must be maintained to provide adequate growth and yield), and (3) a stand structure goal, in terms of diameter distribution, that will provide for regeneration, growth and development of the replacement trees. From these criteria, it can be seen that simply cutting scattered mature trees throughout a stand is not an application of the single-tree selection method because it does not control stand density nor does it regulate the stand structure.

Logging Considerations.—Increased use of the shelterwood method in mixed conifer forest types requires the skillful application of improved logging techniques designed to minimize damage to the residual overstory and the regeneration. In many mixed conifer stands, the seed cut has been completed and natural regeneration established; however, this is only half the reforestation job. Unless the residual overstory can be removed without unacceptable loss and damage to the regeneration, all the time and effort involved in securing regeneration will be wasted, and the area may as well have been clearcut and planted in the beginning.

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[11]Personal communication from Philip McDonald, USDA Forest Service, Pacific Southwest Forest and Range Experiment Station, Berkeley, California. Based on response of regeneration in group-selection cuttings in west-side Sierra Nevada mixed conifer type in northern California.

Logging methods to reduce loss and damage to reproduction have been suggested by Gottfried and Jones (1975). They include:

1. Marking and clearing skid trails.—Skid trails should be marked on the ground and used for all cuts. Pushing tree-length windfalls out of trails does considerable damage to the reproduction. This can be avoided by sawing the blowdown into sections and pushing the sections into areas where they will cause the least damage.
2. Directional falling and variable log lengths.—Trees should be felled into openings in a herringbone pattern so logs can be pulled onto skid trails with the least disturbance. Where a strict herringbone pattern cannot be maintained, the trees should still be felled into openings. Trees laying at a poor angle for winching to skid trails should then be bucked into 16-foot logs rather than being skided in 32-foot logs. Tractors should stay on trails and back toward direction of fall.
3. Winching.—Restricting tractors to marked and pre-cleared skid trails requires more winching. Logs being winched sometimes catch on down material and drag it sideways, destroying and damaging regeneration. The swamper or choker setter can saw out sections that lie in the way, making winching easier and reducing damage.
4. Yarding unmerchantable material.—Moving unmerchantable logs to landings reduces the amount of slash that must be disposed of.
5. Season.—Logging on snow reduces root damage and destroys fewer trees. Logging operations should not be conducted, if possible, during spring when terminal shoots are tender and easily broken or when freezing conditions make stems brittle.

In addition to careful logging, good communication between the timber purchaser and the land owner or manager is the key to satisfactory logging. The best silvicultural prescription will not achieve its objectives if the logger does not understand what is expected of him and desire to accomplish these goals. Because many loggers have little experience with logging methods designed to save regeneration, brief training sessions for sawyers, skidders, swampers, and choker setters would probably help achieve the prescribed objectives.

Closely related to good communication is good sale administration. This requires close supervision of logging and incorporating standards in the contract which minimize damage.

Failure to attain silvicultural objectives may result from a poor prescription, poor marking, an inadequate contract, poor sale administration, or a careless logging job. If any of these jobs is not done properly, the results will likely be damaging to the residual overstory and the regeneration.

Slash Treatment.—Timber harvesting in old-growth mixed conifer stands produces considerable slash because of the large volume of defective material in the true firs. Utilizing residues is the best way to dispose of this material, but at the present time there is little demand for this residue. Using logging residues as fuel for electric generating plants appears to be promising but material less than 3 inches in diameter should not be removed from the harvested area because the foliage and smaller branches are rich with nutrients that can be returned to the soil.

Slash and its treatment can have both desirable and undesirable effects on timber management activities. Unfavorable effects of slash include these:

1. It increases the fire hazard when present in large volumes.
2. It provides breeding material for insects in some situations.
3. Heavy concentrations of slash provide cover for rodents.
4. It is a physical obstruction to planting.
5. In large quantities, it has the potential for creating a nitrogen deficiency in the soil. This is not likely to be serious, however, unless the slash is chipped and incorporated into the soil (Cochran 1968).

There are three important favorable effects:

1. Slash moderates extremes in microclimate at the soil surface thus improving conditions for seedling establishment (fig. 10).
2. As slash decomposes, nutrients are returned to the soil.
3. Decomposing woody residues provide important sites for nonsymbiotic nitrogen fixation and for ectomycorrhizal activity, particularly during dry periods or on dry sites (Harvey et al. 1979).

Slash can be treated in many ways. The method selected depends on factors such as the regeneration method (clearcut or shelterwood) and markets for residues. It is important to keep in mind that slash should be treated only to the extent necessary to satisfy land management goals. Complete slash disposal is neither necessary nor desirable.

Figure 10.—Natural grand fir regeneration established in the shade from slash. Deschutes National Forest, Oregon.

Clearcutting creates the largest amount of slash and also permits the greatest flexibility in choice of residue treatments (Seidel 1974b). Any method suitable for the terrain may be used since no constraints are imposed by residual overstory or reproduction. Slash may be treated by:

1. Broadcast burning.—Broadcast burning is inexpensive but requires skill and experience to attain the desired results (Martin 1976). It reduces the hazard of wildfire, and unburned bole sections provide shade over the area. In high elevation mixed conifer types, the time available for broadcast burning is limited because high fire danger in summer and early rain or snow in fall prevent burning. Broadcast burning after clearcutting can result in a large amount of woody vegetation, such as snowbrush and manzanita, because seed germination is stimulated by fire. It may be possible to reduce these woody species, however, by making one or more preharvest broadcast burns. Such burns could first cause the seed to germinate, then kill the resulting vegetation before it began to compete with seedlings planted after the harvest cut (Martin 1979). More information is needed on the effect of broadcast slash burning on understory vegetation in mixed conifer plant communities.

   Burning also results in a loss of nitrogen from residues because the nitrogen is volatilized by the fire. Although no information is available for the Pacific Northwest, studies in other regions show that this loss is compensated for by nitrogen fixation in the soil stimulated by increased nutrients in the ash (Jorgensen and Wells 1971).

2. Machine piling and burning.—This method is more expensive than broadcast burning, but it reduces the chance of fire escaping and increases the period during which burning can be done. It provides good seed bed scarification but may compact soil. It also tends to remove most of the slash, thus eliminating slash needed on clearcuts for seedling protection. Piling slash also removes nutrients from most of the area. On areas where slash piles have been burned, seedling establishment may be reduced because soil properties are impaired by extreme heat.

3. Crushing and shredding.—This treatment reduces fire hazard but may not clear an area sufficiently for planting. For best results, this treatment should be used in conjunction with tree-length logging to a 4-inch top diamater or yarding unmerchantable material, since larger material is not effectively broken. Machines commonly used for this type of slash treatment are the "Tomahawk,"[12] the "Marden Brushcutter," and "Tree Eater."

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[12]Mention of trade names does not imply endorsement by the U.S. Department of Agriculture.

4. Burying.—Burying slash effectively clears an area and provides good seed bed scarification but may immobilize nitrogen in the soil, reducing growth of regeneration. It is probably best used in areas where esthetic considerations or smoke problems prevent other residue treatments. When slash is buried, an effort should be made to replace upper soil horizons at the surface.

5. Chipping.—Chipping is expensive but speeds the return of nutrients to the soil by increasing decomposition rates. Chipping also lowers the fire hazard.

Treatment of residues resulting from the shelterwood system depends upon the stage of cutting. If advance reproduction is lacking or if it is infected by mistletoe, and the logging operation is a seed cut, then most methods of residue treatment are suitable, provided damage to the residual overstory is avoided. Care must be taken to pile residue far enough from residual trees to prevent scorching when piles are burned. Removing crown with top logs is one method of reducing slash. This method provides good seed bed scarification but has the disadvantage of removing the needles, twigs, and small branches that contain nutrients needed to maintain soil fertility.

Slash in a shelterwood system should also be treated in a way which causes the least damage to established reproduction. Falling trees into openings during logging will minimize damage to regeneration during slash piling operations. Using equipment other than tractors with brush blades can greatly reduce damage. Barrett et al. (1976) found that using a rubber-tired tractor equipped with a front-end grapple reduced damage to ponderosa pine advance reproduction. There was less damage because slash was lifted over the reproduction rather than being pushed through it. This method also has the advantage of not completely removing all slash, since smaller pieces fall through the forks of the grapple. Other ways to minimize damage to regeneration are to hand-pile and burn the slash or to lop and scatter it. Although hand treatment of slash is the most effective way to preserve the reproduction, labor costs are high and people willing to do the work may be difficult or impossible to find.

Slash treatment affects not only timber management but also has impacts on range management, wildlife, insects, diseases, and other forest resources. A systematic approach to residue management which integrates effects on these resources has been developed by Pierovich et al. (1975). In this approach, the land manager is referred to guideline statements that are stratified by type of ownership, management activity, geomorphic province, and species association.

In conclusion, there is a wide variety of possible slash treatment methods. From a silvicultural viewpoint, the method chosen should minimize damage to residual trees and regeneration and maintain soil fertility. This is best achieved by treating slash only to the extent necessary to reduce extreme fire hazards.

Growth and Yield of Managed Stands

Managed stands are those undergoing manipulation to meet some goal, usually to produce a "target" number of trees of a given species of defined diameter and height by a specific time. This goal is often attained through some combination of precommercial and commercial thinning and perhaps suppression of competing vegetation early in the life of the stand.

To define management goals and methods of attaining them in a particular stand, the manager needs the ability to assess site quality and predict tree development for that site. The simplest case confronting the land manager is an even-aged stand of a single species.

Even-Aged Stands.—Site index and height growth curves for Douglas-fir and white or grand fir in managed, even-aged mixed conifer stands are available (figs. 11 and 12) (Cochran 1979b, 1979c). The site index curves are used to forecast potential production from current height and age. Height growth curves are used to estimate height of the tallest trees and used in constructing yield tables (Curtis et al. 1974). Some information on net and gross yields for these species is also available (Cochran 1979a).

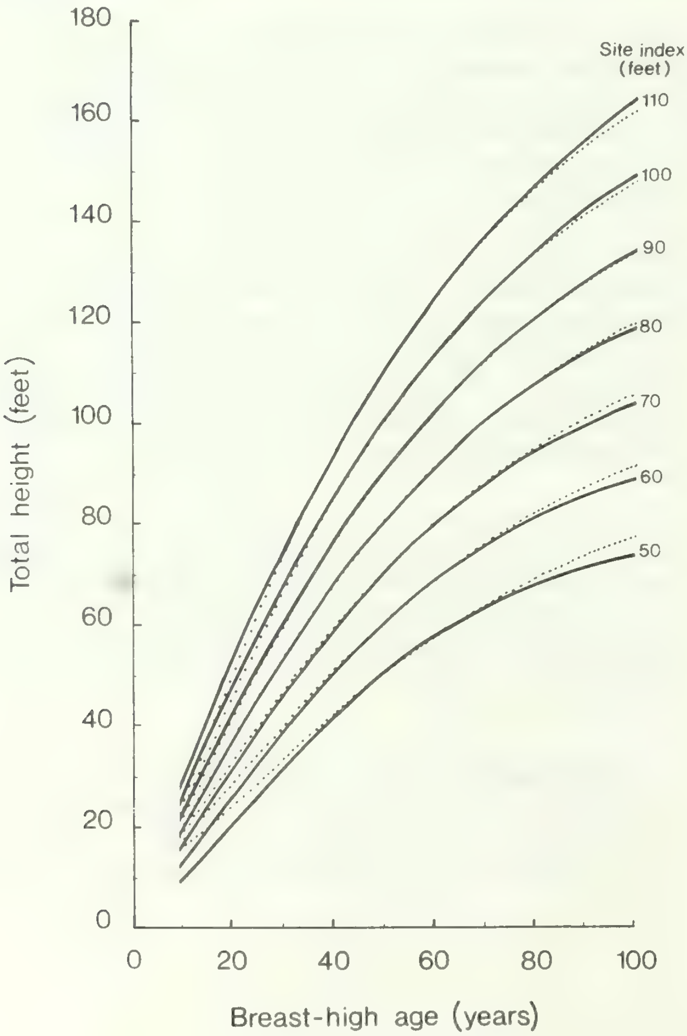

Figure 11.—Site index (solid lines) and height growth curves (dotted lines) for Douglas-fir in managed, even-aged stands east of the Cascades in Oregon and Washington. (Reproduced from Cochran 1979b.)

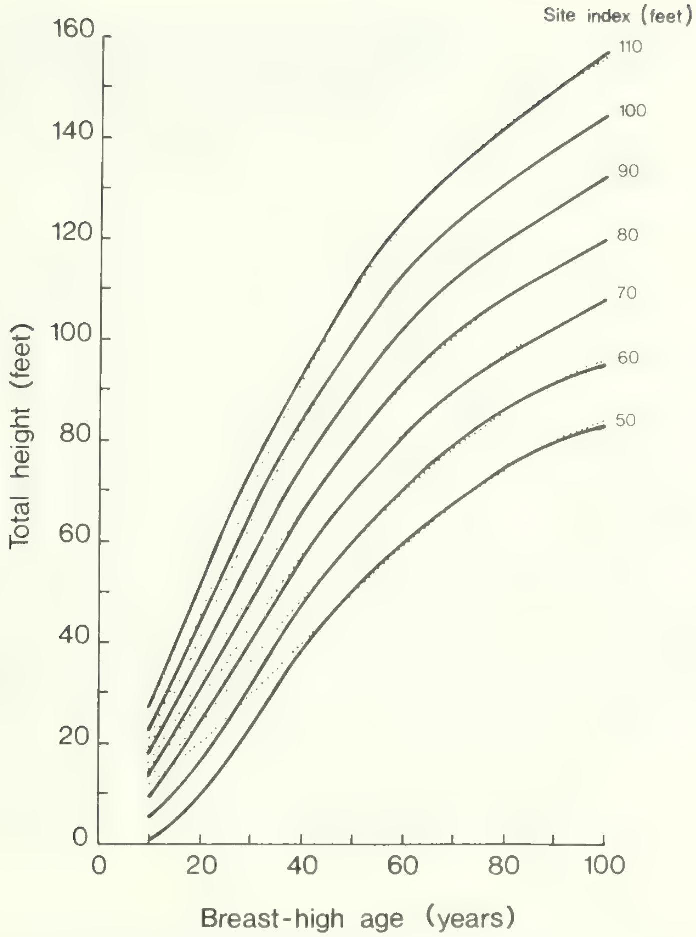

Figure 12.—Site index (solid lines) and height growth curves (dotted lines) for white or grand fir in managed, even-aged stands east of the Cascades in Oregon and Washington.(Reproduced from Cochran 1979c.)

For the range of site indexes, net basal area at 100 years varies from 149 to 322 square feet per acre for Douglas-fir and from 266 to 379 square feet per acre for white or grand fir. Net volumes at these ages and site indexes range from 3,378 to 16,605 cubic feet per acre for Douglas-fir and from 6,839 to 18,940 cubic feet per acre for white or grand fir. These net volume yields are about 76 percent of the gross volume yields for Douglas-fir and 59 to 71 percent of the gross volume yields for white or grand fir.

Except for Cochran's (1979b, 1979c) curves for Douglas-fir and grand (white) fir, Barrett's (1978) curves for ponderosa pine, and Dahms' (1964) curves for lodgepole pine, no site index curves or yield tables have been developed for the other mixed conifer species in eastern Oregon and Washington. The site index tables now used for Shasta red fir, western white pine, western larch, and Engelmann spruce are given in the silvicultural examination and prescription handbook (see footnote 9, p. 31).

The table for red fir is based on Schumacher's (1928) data collected in northern California; the white pine table is based on Haig's (1932) data collected in Idaho and Montana. The larch table, derived from data collected by Cummings (1937) in the intermountain region, is given in curve form by Schmidt et al. (1976). The spruce table is based on unpublished data collected in the intermountain region.

Site index and height growth curves for mountain hemlock are available for some plant communities (Johnson 1980). No other yield data are available, and use of western hemlock yield tables (Barnes 1962) may result in considerable overestimation of growth and yield (Herman and Franklin 1976). In pure mountain hemlock stands, we suggest using mountain hemlock site index curves and western hemlock yield tables, coupled with field checks, to determine the adjustment necessary for mountain hemlock yield in the area of interest. In mixed stands, site index curves and yield tables available for other species may also be used.

Intermediate cuttings (primarily thinnings) are essential in many mixed conifer types to maintain or improve growth and vigor. Timely thinnings result in (1) concentrating growth on fewer higher quality trees, (2) salvaging mortality, (3) maintaining vigorous trees that are more resistant to damaging agents such as insects, wind, and snow, and (4) reducing the amount of slash.

To plan a thinning program, the land manager must answer questions such as (1) when should thinning be done, (2) what type of thinning, and (3) what thinning intensity is needed? These questions are closely related, especially the timing and intensity of thinning.

The stands that benefit most from thinning are young, even-aged stands of seral species such as larch and lodgepole pine. Many naturally regenerated stands are overstocked and need an early precommercial thinning. For larch, the greatest gains occur when trees are about 10 years old and from 10 to 15 feet tall, before competition reduces crown size (Schmidt 1966). Other species also benefit from early precommercial thinning. Land managers should keep in mind that thinning young larch stands creates conditions favorable for the establishment of associated shade-tolerant species, so additional cleanings or weedings may be needed if a single-storied larch stand is desired.

The thinning method will depend to a large degree on stand structure and age. Generally, low thinning (thinning from below) is recommended in even-aged stands. These thinnings remove the suppressed and intermediate trees that are slower growing and less vigorous (fig. 13). Light crown thinning may be used with low thinning as the initial treatment in stands where the crown canopy is uniform in order to open up the canopy. Selection thinning (thinning from above) is not recommended because this leaves the smaller trees that are unable to respond quickly to the increased growing space. These trees are also more subject to mortality from wind and snow (Seidel 1975).

Figure 13.—An even-aged, 33-year-old western larch pole stand after it was thinned from below to a basal area of 50 square feet per acre. Wallowa-Whitman National Forest, Oregon. (Reproduced from Seidel 1977a.)

Thinning intensity (as well as timing) depends on many factors. These include (1) rotation age, (2) species, (3) expected growth rate, (4) present and future markets for small trees, (5) risk of damage to the stand, (6) schedule of future thinnings, and (7) multiple use considerations. The most important factor affecting the intensity of precommercial thinnings is the manager's estimate of tree size (d.b.h.) that will be merchantable in the future. By leaving a high stand density, the silviculturist is assuming that smaller trees will provide a commercial thinning in the future; conversely, leaving a stand of a low density implies that larger trees are needed for a commercial thinning. In other words, the larger the trees needed for a commercial thinning, the fewer that should be left after the precommercial thinning. After a stand has reached merchantable size, goals are to utilize mortality and maintain good volume and diameter growth. Obviously, it is not possible to maximize both diameter growth per tree and volume growth per acre because maximum diameter growth occurs at low stand densities while high densities result in maximum total volume (fig. 14) (Seidel 1977a). Thus, if the management objective is to obtain a relatively high volume per acre, stands should be thinned lightly. If, on the other hand, the aim is to shorten the rotation—sacrificing some volume growth—a heavier thinning is required.

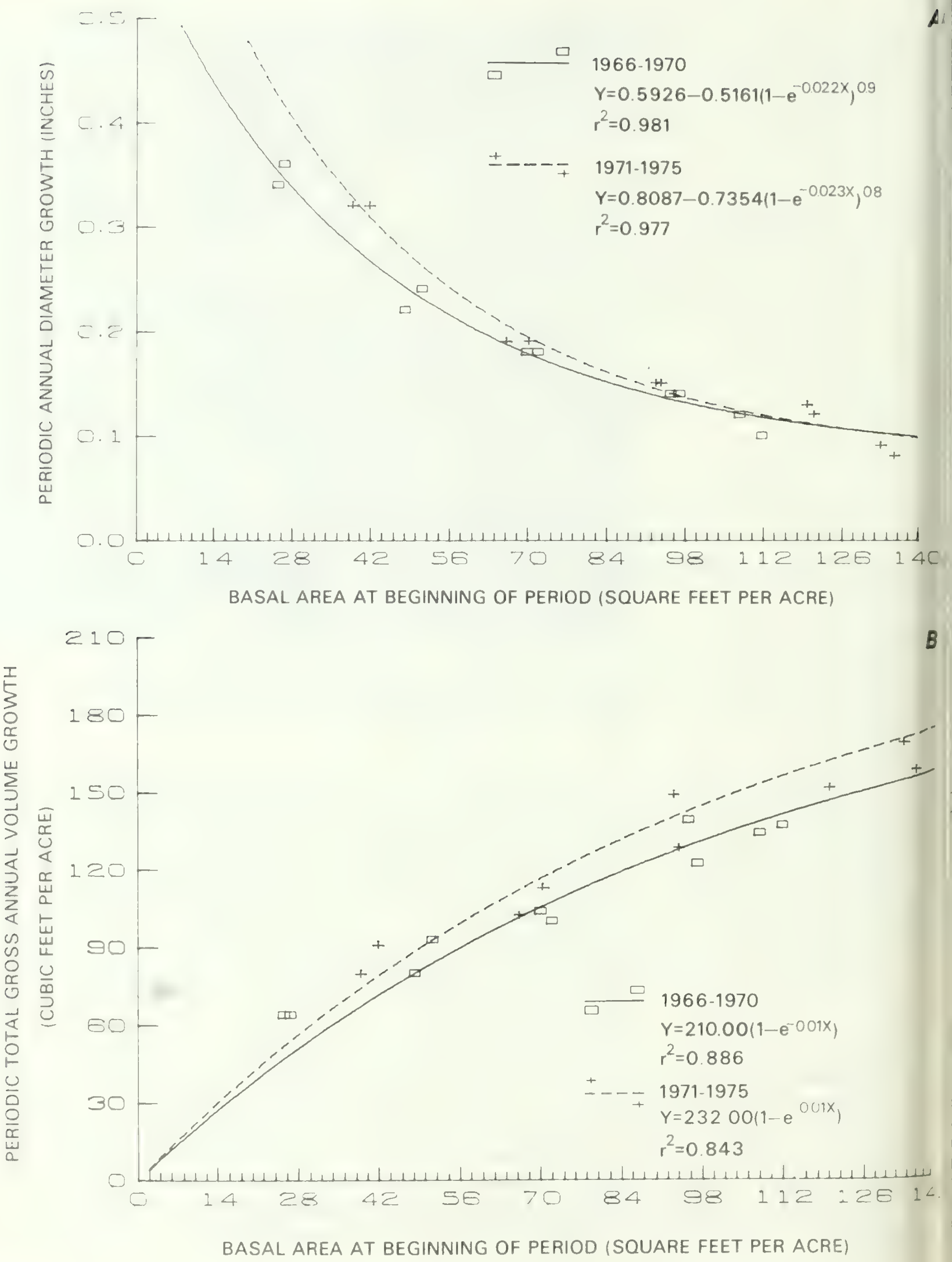

Figure 14.—Periodic annual growth of 33-year-old western larch by density level (basal area) and growth period, site index 80: *A*, Diameter growth; (Reproduced from Seidel 1977a, fig. 3); *B*, Cubic volume growth; (Reproduced from Seidel 1977a, fig. 8).

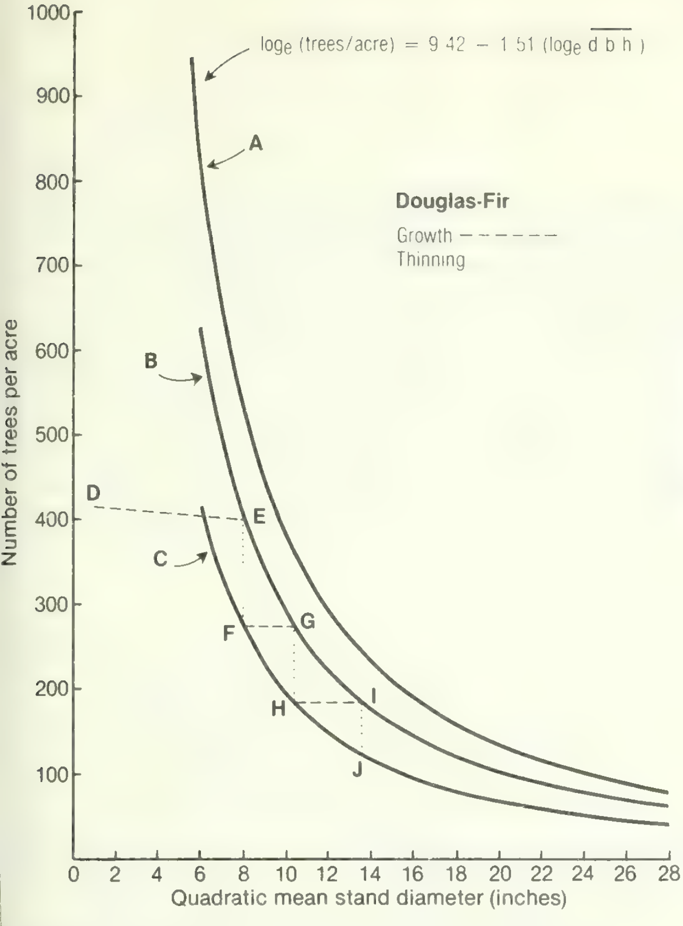

Figure 15.—Stocking level curves for managed, even-aged, east-side Douglas-fir with an illustration of a thinning regime beginning with a precommercial thinning at an average diameter of 1 inch and the first commercial thinning at 8 inches. Curve A represents full stocking, curve B represents the recommended maximum stocking level for managed stands, and curve C represents the recommended minimum stocking level after commercial thinning. Stand density should be regulated during the rotation by thinning to the C curve whenever the average stand diameter for a given number of trees reaches the B curve.

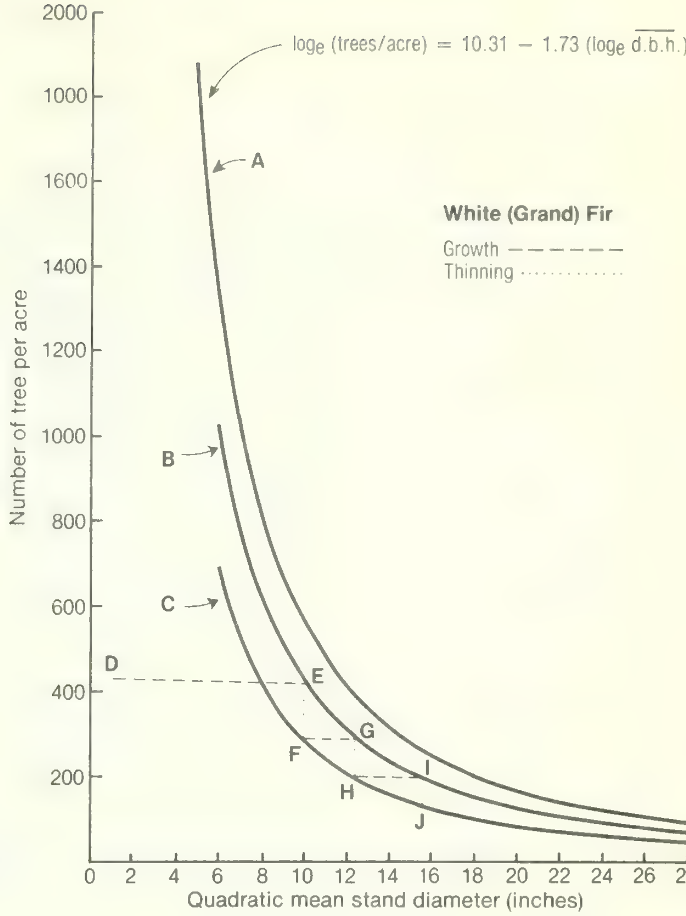

Figure 16.—Stocking level curves for managed, even-aged, east-side white or grand fir with an illustration of a thinning regime beginning with a precommercial thinning at an average diameter of 1 inch and the first commercial thinning at 10 inches. Curve A represents full stocking, curve B represents the recommended maximum stocking level for managed stands, and curve C represents the recommended minimum stocking level after commercial thinning. Stand density should be regulated during the rotation by thinning to the C curve whenever the average stand diameter for a given number of trees reaches the B curve.

Stocking level cures have been prepared for even-aged, east-side Douglas-fir (fig. 15) and white (grand) fir (fig. 16). For each set of curves, the upper curve A corresponds to the best fit of $\log_e$ (trees per acre) = a + b ($\log_e$ quadratic mean diameter) (Reineke 1933), and represents full stocking.[13] The middle curve B represents a stocking level equivalent to 75 percent of the upper curve. At or below this stocking level, suppression and suppression mortality should be minor. The lower curve C (67 percent of the middle curve) represents a stocking level that we believe is reasonable after commercial thinning, provided the thinning is mostly from below and vigorous trees are left. This level will concentrate most of the potential production on trees which eventually will be harvested in thinnings or harvest cuttings, provided no other damage not directly related to stand density occurs.

[13]Curves derived from data on file at the Silviculture Laboratory, Pacific Northwest Forest and Range Experiment Station, Bend, Oregon.

In using these curves, the manager should regulate stand density so it varies between the C- and B-level curves after the first commercial thinning. An example is given in figure 15. It assumes one precommercial thinning in a Douglas-fir stand at an average diameter of 1 inch and the first commercial thinning at 8 inches. The precommercial thinning would reduce the number of trees to about 415 per acre (point D) allowing for mortality of about 15 trees per acre before commercial entry. When the average diameter reaches 8 inches (E), the stand would be commercially thinned to about 270 trees per acre (F). Another commercial thinning would be indicated when the average diameter intersects the B curve at about 10.5 inches (G). In this thinning, the number of trees would be reduced to about 180 per acre (H). A third commercial thinning to about 125 trees per acre (J) is suggested at an average diameter of 13.5 inches.

A similar example is shown in figure 16 for a white (grand) fir stand. It assumes a precommercial thinning at a 1-inch diameter and the first commercial thinning at 10 inches. These illustrations are only two of many possible thinning regimes. The number of trees left after a precommercial thinning depends mainly on the diameter of trees that will be merchantable in the commercial thinning. Therefore, if the first commercial thinning is possible when average diameter is 8 inches instead of 10 inches, for example, about 630 trees per acre should be left after precommercial thinning in a white fir stand. This is the number of trees at the point where the B curve intersects the average stand diameter that will support a commercial thinning, plus a small (2- to 4-percent) allowance for mortality. Site index and age are not given with the curves because diameter is more dependent on past stand history than age for any given site, and recommended stocking levels are largely independent of site.

For western white pine and western larch, we recommend stocking levels similar to Douglas-fir; Engelmann spruce stocking levels are thought to be very close to those for white (grand) fir.[14] For stands which are mixtures of several species, we suggest using a weighted average of the appropriate curves with the weights being the fraction of each species the manager wishes to retain after thinning. Note that the stocking level curves do not indicate rates of growth. Growth rates (Cochran 1979a) should be considered when making decisions concerning thinning, and economics may rule out any kind of thinning on poorer sites.

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[14]Curve forms of $\log_e$ (trees per acre) = a + b ($\log_e$ quadratic mean diameter) were derived for western white pine, western larch, and Engelmann spruce from data collected in the Rocky Mountains. Curves for white pine and larch compare closely with eastern Oregon and Washington Douglas-fir, whereas curves for Engelmann spruce compare closely with grand fir data. We assume that the relative number of suppressed trees in normal stands of white pine, larch, and spruce are similar to Douglas-fir and white (grand) fir.

Silviculturists should keep in mind that acceptable stocking levels encompass a range of stand densities. Therefore it is not critical to maintain an exact stand density at any time in the rotation. The important point is to thin the stand sufficiently to prevent excessive competition which results in smaller crowns, loss of vigor, and reduced growth.

Uneven-Aged Stands.—In uneven-aged stands most trees undergo periods of suppression. Thus site index and height growth curves may have little meaning. Further, averages of age, basal area, and volume have no relationship to the site index, age, basal area, and volume relationships for managed, even-aged stands. One method of predicting growth and yield of these complex stands is to use a simulation model based on individual trees. At present two simulation models appear applicable to mixed conifer stands of uneven age. One of these models has been developed by Stage (1973), and other by Botkin et al. (1972).

These models have a set of functions that predict changes in individual tree diameters, heights, and crowns, with time, for specified stand conditions. Periodic mortality, scheduled harvest, and tree damage are also included. To use these models outside the areas where they were developed, the manager should define and plug individual functions into the desired model. For short-term projections, the models can be calibrated during stand examination. This calibration allows for raising or lowering projected growth rates by a factor equivalent to recent stand growth rate divided by predicted stand growth rate from the model.

To use Stage's prognosis model, the manager must supply:

1. Site characteristics: slope, aspect, elevation, habitat type.
2. Stand characteristics: density (crown competition factor, basal area, trees per acre), diameter distribution by species.
3. Tree characteristics: diameter, height, crown ratio, and species.

Use of the prognosis model east of the Cascades in Oregon and Washington requires approximation of comparable habitat types plus the calibration features incorporated in the model.

A commitment to uneven-aged management requires stand treatments to create a distribution of age and size classes that will allow the desired level of periodic tree removal consistent with growth rates. As we discussed previously, the land manager must consider three factors for uneven-aged regulation: (1) a maximum tree size goal, (2) the residual basal area level that should be maintained, and (3) the stand structure or diameter distribution goal.

The most widely accepted procedure for establishing a diameter distribution goal is to utilize a quotient Q (Marquis 1977). Q is related to diameter class and the number of trees per unit area in a given class. A balanced diameter distribution implies that the number of trees in successive diameter classes follows a geometric series of the form M, MQ, MQ^2, MQ^3—where M is the number of trees in the largest diameter class. Q values (for 2-inch diameter classes) ranging from 1.3 to 2.0 have been recommended for various situations. Stands maintained at small Q values have a higher proportion of available growing space in large trees. These stands may require periodic removal of many small trees in the diameter class where unregulated growing stock crosses the threshold into the portion of the stand to be regulated (Alexander and Edminster 1977b).

The cutting cycle depends on growth rate, residual stocking levels selected, site quality, and the amount of merchantable volume left for cutting. The projected allowable cut is the difference between the residual goal and the estimated stocking (Marquis 1977). Curtis (1977) cites several references to short-term projections for uneven-aged stands and points out many difficulties involved in yield estimations. Some approximations of stocking levels, maximum tree sizes, cutting cycles, and even Q values for Douglas-fir and white or grand fir can be obtained from the stocking level curves for even-aged stands. Such approximations assume that uneven-aged stands are merely mixtures of components of even-aged stands. We have serious doubts about the validity of such estimates because when species are mixed on the same area the growth rates of various age classes probably differ from the growth rates of those same age classes and species in a pure, even-aged stand.

The application of uneven-aged silviculture and management is difficult because information on growth and regeneration in relation to stocking and stand structure is lacking. Until more data becomes available, the best summary of current applicability of uneven-aged silviculture and management in the West is found in the proceedings of a workshop on uneven-aged silviculture and management (USDA Forest Service 1977).

Multiple-Use Silviculture

In addition to their value as a source of timber for the wood-using industries of the area, the mixed conifer forests of eastern Oregon and Washington are of great importance in providing water, habitat for many species of wildlife, forage for livestock, and recreation opportunities. As population increases and more land is set aside for restricted use (i.e., Wilderness Areas), the pressure for multiple-use management on the remaining forests increases. It is important for land managers to realize that any alteration of forest habitats for silvicultural purposes also affects wildlife populations, water yields, and esthetic quality. Timber management is, in effect, management of wildlife, watersheds, and recreation. Fortunately, in most cases, timber management objectives can be compatible with multiple-use objectives.

Water.—Hydrologic studies of forested watersheds in the United States have all resulted in the conclusion that streamflow increases as stand density is reduced because of reduced transpirational drain on soil moisture. On one central Oregon watershed, Berndt and Swank (1970) reported an increase of 2.21 inches in the average annual water yield, which coincided approximately with the onset of heavy timber harvesting. They also found a decrease of 1.18 inches in average water yield 16 years later. They attributed this to increased stocking by second-growth stands and a reduction of timber harvest.

No studies of the effect of various cutting methods on water yield have been conducted on mixed conifer watersheds in eastern Oregon and Washington, but work in the Rocky Mountain subalpine forests has provided guidelines for improving water yield which may be useful in the eastern Oregon-Washington region (Leaf 1975). Patterns of optimum snow accumulation resulted from patch clearcutting when patches had a diameter 5-8 times the height of surrounding trees and were spaced about the same distance apart. Because of the more rapid snowmelt in the clearcuts, streamflow was increased in spring and early summer. Average annual water yields increased at least 2 inches when 40 percent of the watershed was clearcut in patches and 60 percent was left uncut; flood peaks were not significantly increased when not more than 50 percent of the watershed was clearcut.

Range and Wildlife.—Habitat for big game and domestic livestock in old-growth mixed conifer stands can be greatly improved by silvicultural practices which increase forage and provide adequate thermal and hiding cover. The cutting method which creates these conditions is the same as that which optimizes water yields—small patch clearcuts distributed throughout the uncut stand. The clearcuts provide palatable forage for deer, elk, and cattle, and the adjacent uncut stands provide cover. Partial cut stands are preferred least by deer and elk because they lack the volume and variety of forage in clearcuts and the cover of the uncut stands (Edgerton 1972). Recommendations for improving livestock utilization of mixed conifer forests are given by Hedrick et al. (1968).

Thomas et al. (1979b) recommend a ratio of 40-percent cover to 60-percent openings for deer and elk to optimize use of the maximum area on summer ranges in the Blue Mountains. A distance of 600-1,200 feet between openings is suggested as optimum requirement for cover. Size of the clearcuts should not exceed 40 acres since deer and elk will not forage over larger areas (Dealy 1975). Domestic livestock, however, will forage over openings of any size. Detailed information on the effect of timber management on deer and elk habitat in the Blue Mountains is given by Black et al. (1976) and Thomas et al. (1979b).

Timber management also affects the habitat of other wildlife species. After reviewing the effect of intensive forest management on birds, Thomas et al. (1975) concluded that present trends in timber management will lead to stand diversity resulting in a greater variety of bird species, except for those species adapted to old-growth and those requiring snags for nesting. Estimates of the number of snags needed to maintain populations of snag-dwelling species in the Blue Mountains have been prepared by Thomas et al. (1979a). To provide sufficient snags for these species, it may be necessary to retain snags that might otherwise be salvaged and to create snags by killing suitable trees. Longer rotations of selected trees or stands can also provide the larger diameter snags required by some species.

Recreation and Esthetics.—The scenic quality of forested landscapes is affected by timber management. In general, scenic quality is enhanced by variety and diversity in the landscape (USDA Forest Sevice 1973). Esthetic quality is usually highest in partially cut stands and lowest in clearcuts and uncut old-growth stands. The visual quality of clearcuts can be improved by irregular openings that have form and texture similar to the surrounding stands and thus complement the natural landscape (USDA Forest Service [In press]).

In areas of high recreational use near campgrounds and lakes, uneven-aged management (single-tree or group selection) can minimize the visual impact of logging and yet provide variety in stands.

The ephemeral quality of many landscapes in eastern Oregon and Washington can be greatly increased by maintaining or increasing the larch component of mixed conifer stands because of the fall color of larch.

RESEARCH NEEDS

Because of the multiple uses of mixed conifer forests, the most important need in research is to integrate silvicultural research with other disciplines in a holistic approach toward forest management. As more information is available from multidisciplinary research, land managers will be better able to predict the effects of silvicultural prescriptions not only on tree regeneration and growth but also on the probability of insect or disease attack, on soil nutrient balance, and on habitat for wildlife and domestic livestock. Specific problems that need attention are:

1. Response of suppressed true fir seedlings and saplings to release in various plant communities and the characteristics of trees that respond rapidly.
2. Reactivation of decay-causing fungi in suppressed true fir saplings wounded during overstory removal.
3. Use of uneven-aged management in plant communities where regeneration of shade-tolerant species is prolific. This involves the effect of stand structure and composition on the establishment, growth, and composition of regeneration, and the potential growth and yield under various stand structures.
4. Refinement of stocking-level curves for mixed species stands.
5. Development of site-index curves and yield tables for managed stands of Engelmann spruce, western white pine, and mountain hemlock.
6. Development of techniques to simulate the effects of thinning regimes on growth and yield in both even-aged and uneven-aged stands of mixed species.

7. Economic analyses of silvicultural and management alternatives.
8. Use of prescribed burning in mixed conifer communities and its effect on vegetation, soil nutrient status, insects, and disease.
9. The long-term effects of increased utilization of logging residues on nutrient balance of the soil and forest productivity.

METRIC EQUIVALENTS

1 inch = 2.54 centimeters
1 foot = 0.3048 meter
1 mile = 1.61 kilometers
1 acre = 0.4047 hectare
1 pound = 0.4536 kilogram
1 tree per acre = 2.47 trees per hectare
1 square foot per acre = 0.2296 square meter per hectare
1 cubic foot per acre = 0.0700 cubic meter per hectare
°C = 5/9 (°F − 32)

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Appendix

Common and Scientific Names of Plants, Vertebrates, Insects, and Diseases[1]

PLANTS

Douglas-fir	*Pseudotsuga menziesii* (Mirb.) Franco
Douglas-fir (Rocky Mountain)	*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco
Engelmann spruce	*Picea engelmannii* Parry ex Engelm.
Fir	
Grand fir	*Abies grandis* (Dougl. ex D. Don) Lindl.
Shasta red fir	*Abies magnifica* var. *shastensis* Lemm.
Subalpine fir	*Abies lasiocarpa* (Hook.) Nutt.
White fir	*Abies concolor* (Gord. & Glend.) Lindl. ex Hildebr.
Greenleaf manzanita	*Arctostaphylos patula* Greene
Hemlock	
Mountain hemlock	*Tsuga mertensiana* (Bong.) Carr.
Western hemlock	*Tsuga heterophylla* (Raf.) Sarg.
Pine	
Lodgepole pine	*Pinus contorta* Dougl. ex Loud.
Ponderosa pine	*Pinus ponderosa* Dougl. ex Laws.
Western white pine	*Pinus monticola* Dougl. ex D. Don
Sierra evergreen chinkapin	*Castanopsis sempervirens* (Kell.) Dudl.
Snowbrush ceanothus	*Ceanothus velutinus* Dougl. ex Hook.
Western larch	*Larix occidentalis* Nutt.
Western redcedar	*Thuja plicata* Donn ex D. Don
Willow	*Salix* spp.

INSECTS

Douglas-fir beetle	*Dendroctonus pseudotsugae* Hopkins
Mountain pine beetle	*Dendroctonus ponderosae* Hopkins
Douglas-fir tussock moth	*Orgyia pseudotsugata* (McDunnough)
Fir engraver	*Scolytus ventralis* LeConte
Pine engraver	*Ips pini* (Say)
Larch casebearer	*Coleophora laricella* (Hübner)
Spruce beetle	Dendroctonus rufipennis (Kirby)
Western spruce budworm	*Choristoneura occidentalis* Freeman
Modoc budworm	*Choristoneura viridis* Freeman
(no common name)	*Agathis pumila* (Ratzeburg)
(no common name)	*Chrysocharis laricinellae* (Ratzeburg)
(no common name)	*Dicladocerus westwoodii* Westwood

[1]Sources for nomenclature: trees, Little (1979); shrubs, Garrison, Skovlin, Poulton, and Winward (1976); insects, Furniss and Carolin (1977); and vertebrates, Ingles (1973). There is no standard reference for diseases.

DISEASES

Annosus root rot	*Fomitopsis (Fomes) annosa* (Fr.) Karst.
Bleeding conk fungus	*Stereum sanguinolentum* Alb. & Schw. ex Fr.
Dwarf mistletoe	*Arceuthobium* spp.
Indian paint fungus	*Echinodontium tinctorium* Ell. & Ev.
Laminated root rot	*Phellinus (Poria) weirii* (Murr.) Gilb.
Mottled rot	*Pholiota* spp.
Red ring rot	*Phellinus* (Fomes) *pini* (Thore ex Fr.) Pilat
Red root and butt rot	*Polyporus tomentosus* Fr. var. *circinatus* (Fr.)
Shoestring root rot	*Armillariella mellea* (Fr.) Karst
White pine blister rust	*Cronartium ribicola* Fisch.
Yellow pitted rot	*Hericium abietis* (Weir ex Hubert) K. Harrison
(no common name)	*Bacillus thuringiensis* Berliner

VERTEBRATES

Cattle	*Bos.* spp.
Deer	*Odocoileus* spp.
Deer mouse	*Peromyscus maniculatus* (Wagner)
Elk	*Cervus* spp.
Hare	*Lepus* spp.
Pocket gopher	*Thomomys* spp.
Porcupine	*Erethizon dorsatum* (Linnaeus)
Rabbit	*Sylvilagus* spp.
Sheep	*Ovis* spp.
Voles	*Microtus* spp.

Seidel, K. W., and P. H. Cochran.
1981. Silviculture of mixed conifer forests in eastern Oregon and Washington. USDA For. Serv. Gen. Tech. Rep. PNW-121, 70 p. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

The silviculture of mixed confier forests in eastern Oregon and Washington is described. Topics discussed include ecological setting, damaging agents, silviculture, and management. The relevant literature is presented, along with unpublished research, experience, and observations. Research needs are also proposed.

Keywords: Silviculture, mixed stands, coniferae, timber management, regeneration (stand), eastern Oregon, eastern Washington.

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Agriculture

Forest Service

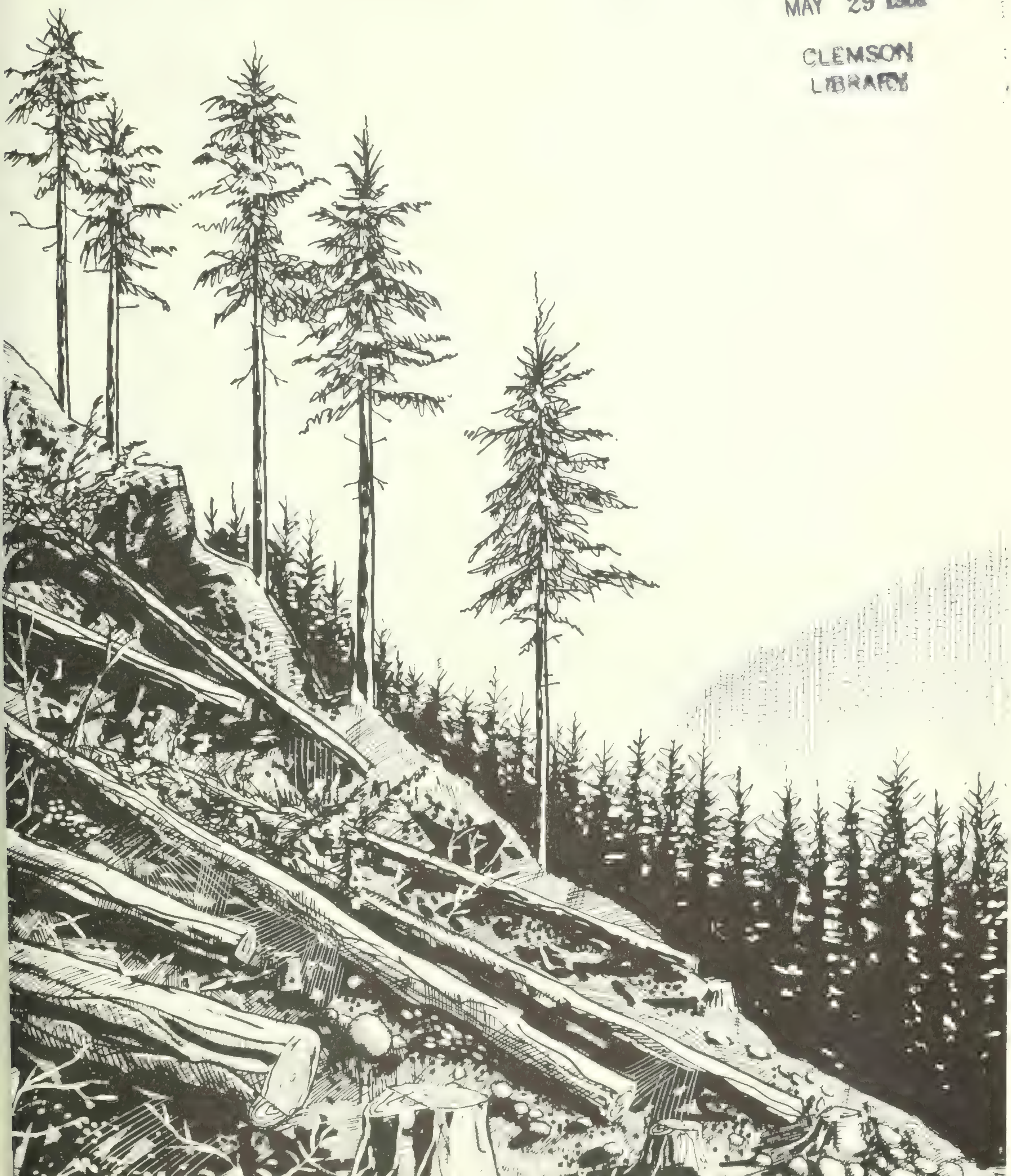
Pacific Northwest
Forest and Range
Experiment Station

General Technical
Report
PNW-122

April 1981

Uphill Falling of Old-Growth Douglas-Fir

Douglas L. Hunt and John W. Henley



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Abstract

Hunt, Douglas L., and John W. Henley. 1981. Uphill falling of old-growth Douglas-fir. USDA For. Serv. Gen. Tech. Rep. PNW-122, 18 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Five timber sales were made in old-growth Douglas-fir with matched cutting units. On one unit of each sale uphill falling by either hydraulic jacks or tree-pulling machine was required; on the other unit free falling was required. Logging equipment and methods were the same in each unit. Uphill falling produced a larger volume of timber at less cost than free falling because breakage was less.

KEYWORDS: Felling operations, old-growth stands, Douglas-fir, Pseudotsuga menziesii.

Contents

Introduction

Two methods of falling timber uphill (directional falling) have become important tools for harvesting timber in the Pacific Northwest. The methods are tree pulling (line pulling) and hydraulic jacking.

In tree pulling, a crewmember climbs a tree and attaches a cable around the bole. The cable is then shackled to another line from a tree-pulling machine. This machine contains a powered drum set with a torque converter and is usually mounted on a truck. After the cable is attached and the climber has descended, the faller puts in an undercut and a backcut. Before the backcut severs all the holding wood (uncut portion of the stump), the crew moves to a safe location and signals the operator of the machine to pull the tree down.

In jacking, the cutter puts two backcuts in the tree, far enough apart to insert jacks. After sawing out the undercut and putting in the jacks, the cutter pumps the jacks by hand or power to tip the tree in the desired direction.

Directional falling is not new. Fallers have always used wedges and holding wood to control the direction in which trees fall when cut. New methods and equipment, however, enable timber cutters to fall trees where conditions are most likely to minimize breakage. Some loggers using tree pulling or jacking methods report that volumes of merchantable timber are higher because breakage is less. Data to substantiate these claims have been lacking. Reliable information on the costs and benefits of directional falling is needed by land managers and timber harvesters making decisions on which method to use. This paper reports results of a study comparing uphill falling with free (conventional) falling.

Procedure

Five timber sales, each containing two or three matched cutting units, were selected from old-growth Douglas-fir timber stands in western Oregon and Washington. Purchasers were required to use tree-pulling or hydraulic jacking methods and equipment to fall trees uphill on one or two of the matched units and to use free fall methods, in the sidehill direction (parallel to the contours), on the other unit.

In the units felled uphill, the lead (falling pattern) was established and maintained by pulling trees or hydraulically jacking them. Usually the falling direction was established at an angle somewhat less than "straight up" or perpendicular to the land contours. Exceptions were made when a change in the falling direction would prevent or minimize breakage--near roads, rock outcrops, and sharp ridges--or to take advantage of draws and ridges.

In the free felled units, the lead was usually established and maintained in a sidehill direction. The cutters used only wedges, holding wood, and special undercuts to maintain the established direction.

The purchaser was required to use the same cutting crew and insure that they felled all units with equal competence. The same logging equipment and procedures were also required for each unit. The objective was to obtain unbiased information on the effects of falling method on breakage and costs.

Units in each sale were as identical in timber characteristics and terrain conditions as possible. Characteristics of the units are summarized in table 1, to show their similarity. Each timber sale is identified by name and project number.

Table 1--Characteristics of cutting units in 5 timber sales of old-growth Douglas-fir

Project No.	Location	Sale name	Cutting unit1/	Size	Slope	Average d.b.h.	Average tree height to a 6-inch top	Defect	Gross volume per acre	G v pe
				Acres	Percent	Inches	Feet	Percent	Thousand board Scribner sca	
03	Illinois Valley Ranger District	Loop Hope	FF	7	35	39	148	4	117	
	Siskiyou National Forest		HJ	8	35	38	164	4	104	
04	Powers Ranger District	Three Way	FF	13	70	38	162	11	100	
	Siskiyou National Forest		TP	13	70	38	157	7	102	
			HJ	16	70	38	154	14	99	
05	Lowell Ranger District	Hobbit	FF	33	65	45	148	39	108	
	Willamette National Forest		TP	25	60	48	166	46	116	
06	Wind River Ranger District	Trout Creek Hill	FF	16	45	38	122	14	130	
	Gifford Pinchot National Forest		HJ	18	50	38	114	14	130	
12	Coos River Area	South Susan Ridge	FF	29	75	42	163	18	106	
	Coos Bay District, Bureau of Land Management		HJ	25	75	42	148	20	113	

1/FF = free or conventional falling; HJ = hydraulic jacking; TP = tree pulling.

2/Stump diameter ≥ 24 inches inside bark.

Percent slope is the average slope from top to bottom of each cutting unit.

Average diameter at breast height (d.b.h.), percent defect, and gross volume (Scribner scale) per acre were taken from cruise data provided by the local administration unit for each sale. The average gross volume (Scribner scale) per tree and the average tree height to a 6-inch top were calculated from cutters' records made when trees were felled.

Figure 1, a view of the Three Way sale shortly after falling was begun, illustrates the preferred layout. Here, three adjacent cutting units are separated only by flagged lines. The Loop Hope and Trout Creek Hill sales were also arranged this way. The cutting units in the Hobbit and South Susan Ridge sales were geographically separated. This arrangement was not ideal but was necessary because no accessible timber stand large enough to be divided into similar cutting units could be found.

Figure 1.--Three Way sale after falling was begun.

Figure 2.--Trout Creek Hill sale timber.

Figure 2 shows the type of old-growth Douglas-fir included in the sales.

Cutters and loggers were required to record data according to instructions from personnel of the Pacific Northwest Forest and Range Experiment Station. Information recorded each day by the logging crew included listing workers by occupation, hours worked, equipment used, and delay time.

Information for each tree recorded daily by the cutters included:

1. Type; i.e., merchantable, cull, standing snag, or windfall.

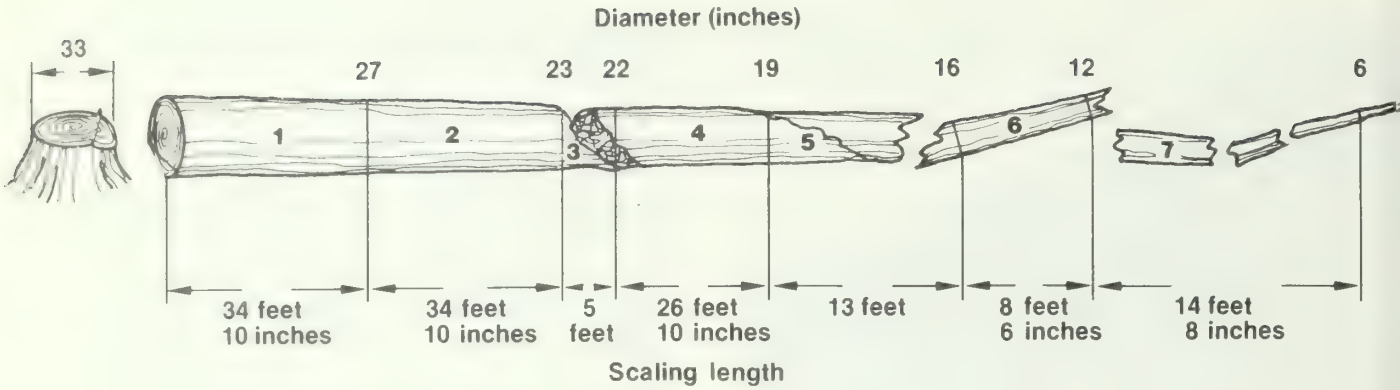
2. Diameter and length of each segment.

3. Segment type; i.e., log, sound break, cull break, or top break.

4. Falling method used.

5. Species.

Log volumes were computed from scaling diameters and lengths. Breakage volumes were computed by scaling diameter and length to the nearest foot. Figure 3 illustrates falling and bucking measurements and codes.



Segment 1: Coded 1, bucked log
Segment 2: Coded 1, bucked log
Segment 3: Coded 3, cull break
Segment 4: Coded 1, bucked log
Segment 5: Coded 2, sound break
Segment 6: Coded 1, bucked log
Segment 7: Coded 4, top break
The remaining segment is beyond the 6-inch top and was not measured.

Figure 3.--Codes by segment.

After these records were keypunched, a computer-edit program identified coding and recording errors which were then corrected. Other computer programs produced lists by tree, log, and breakage. Further analysis of variables was made possible by separating tree type, segment type, falling method, and species.

For statistical analysis, a randomized complete block design was used in which blocks were the entire sale areas and falling methods were the treatments within blocks. Because only one sale area provided three cutting units, four of the five blocks used only two falling methods.

Analysis of variance was used to test the one important contrast among falling methods. This compared uphill falling (both jacking and pulling) with free falling. Results showed uphill falling differed significantly from free falling in all variables tested, except loading productivity.

Results

Breakage Data

All breakage data in this report are from Douglas-fir trees 24 inches or more d.i.b. (diameter inside bark) at the stump. Data for the small understory trees were not included because initial analysis indicated that data from these trees distorted the results. Including data from hundreds of small trees reduced average tree height and length to the first break but contributed nothing to the breakage volume. Deleting small trees provided a more accurate picture of breakage in trees of sizes that concern both timber sellers and purchasers.

Total breakage (including sound, cull, and top) was reduced in units felled uphill compared with free-felled units in all sales except the South Susan Ridge (project 12). The difference in volume lost to breakage ranged from 2 percent to over 5 percent (table 2 and fig. 4). The average reduction in breakage for the five units felled uphill was 3 percent.

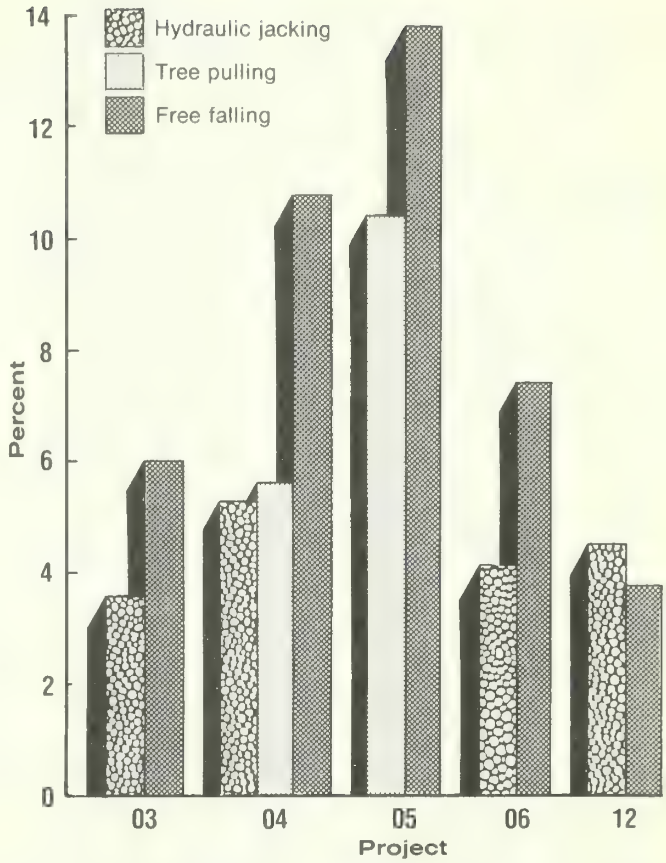


Figure 4.--Percent of cubic volume of tree lost in breakage.

Table 2--Percent of cubic volume lost, by type of breakage

Project	Sale name	Cutting unit[1]	Breakage: Sound	Cull	Top	Total	Difference
			- - - - Percent - - - -				
03	Loop Hope	FF	3.9	0.3	1.8	6.0	
		HJ	2.5	.1	1.0	3.6	2.4
04	Three Way	FF	7.4	1.3	2.1	10.8	
		TP	3.4	.4	1.8	5.6	5.2
		HJ	3.0	.9	1.4	5.3	5.5
05	Hobbit	FF	5.1	6.1	2.6	13.8	
		TP	3.7	6.1	.6	10.4	3.4
06	Trout Creek Hill	FF	2.7	2.0	1.7	6.4	
		HJ	2.2	.4	1.5	4.1	2.3
12	South Susan Ridge	FF	2.2	.3	1.3	3.8	
		HJ	3.1	.4	1.0	4.5	-.7

[1]FF = free or conventional falling; HJ = hydraulic jacking; TP = tree pulling.

This reduction in breakage appears small compared with some previous reports on uphill falling. Experienced foresters using jacks or tree-pulling machines have assumed that the reduction was much higher. Groben (1976) and Kjosness[1/] estimated 10 to 15 percent less loss from breakage; Burwell (1971) stated that 10 percent could be expected but that results appeared better; and Shook[2/] mentioned 5 percent less loss. None of these sources provided data, and Burwell (1971) mentioned that there was no statistical proof available. McGreer (1973) reported savings in breakage from 1.17 to 1.70 percent. The procedures used to measure breakage in this study were those used by McGreer.

The reduction in breakage, though small, was statistically significant and represents a real saving.

[1/]Kjosness, John D. 1977. Up the hill - the benefits of using jacks. Report presented at the 1977 Sierra Cascade Logging Conference, Redding, Calif.

[2/]Shook, Paul. 1974. How to save timber on steep ground. Paper presented at the 1974 Oregon Logging Conference, Eugene.

Contrary to the belief of most cutters and loggers, table 2 shows that not all the savings in breakage or even most of it occurred in the tops of trees. For this study, top breakage was defined as loss of merchantable wood from the last bucking point to a 6-inch or existing top. A top that was rotten or for any reason unmerchantable, was coded as "cull break." Savings in top breakage were found in the six units felled uphill, but they ranged from only 0.2 to 2.0 percent, with an average of 0.7 percent. Savings in sound breakage occurred in five of the six uphill units and ranged from 0.5 to 4.4 percent, averaging 2.3 percent. This indicates that although some volume from the top is saved in uphill falling, more is saved in the lower, more valuable portion of the tree.

The average length of all logs cut, divided by the average length of all trees to a 6-inch top, gave the portion of the average tree recovered in logs (fig. 5). For example, if the length of logs cut from all trees averages 75 feet and the length of all trees averages 100 feet, then 75 percent of the average tree is recovered in logs.

In all five sales, the proportion of trees cut into logs was greater in units felled uphill than in free-felled units. The increase ranged from 1 percent to 9 percent and averaged 5 percent. Statistical analysis of this variable indicates that this increase is significant.

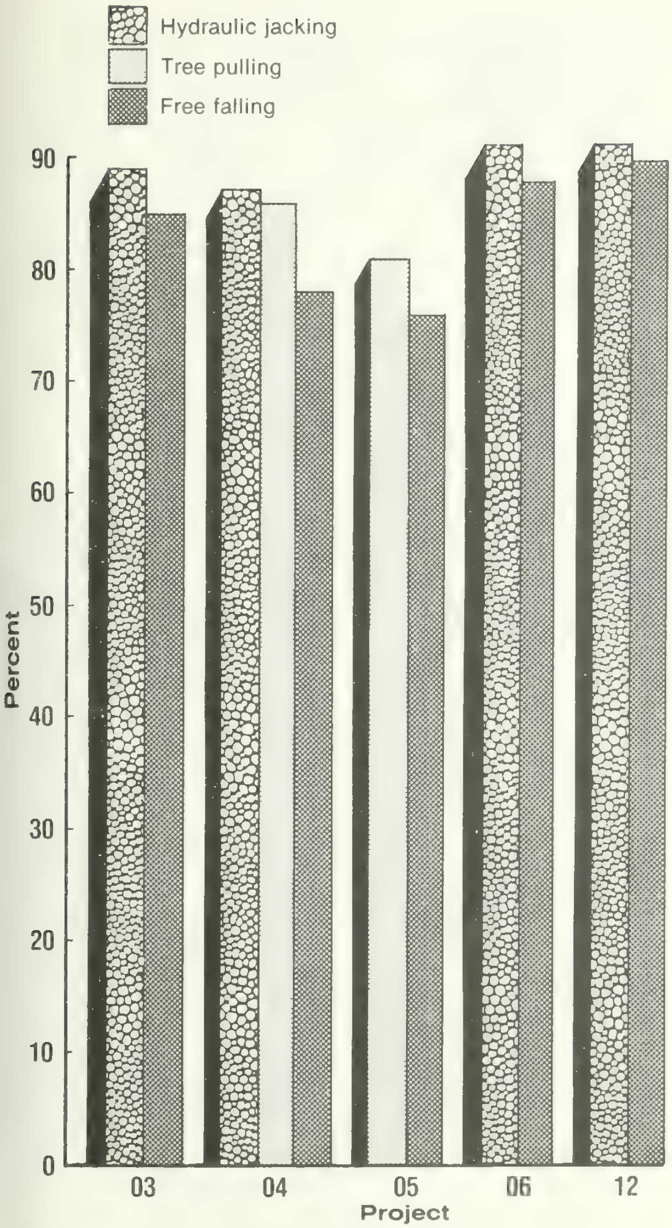


Figure 5.--Percent of merchantable tree length recovered in logs.

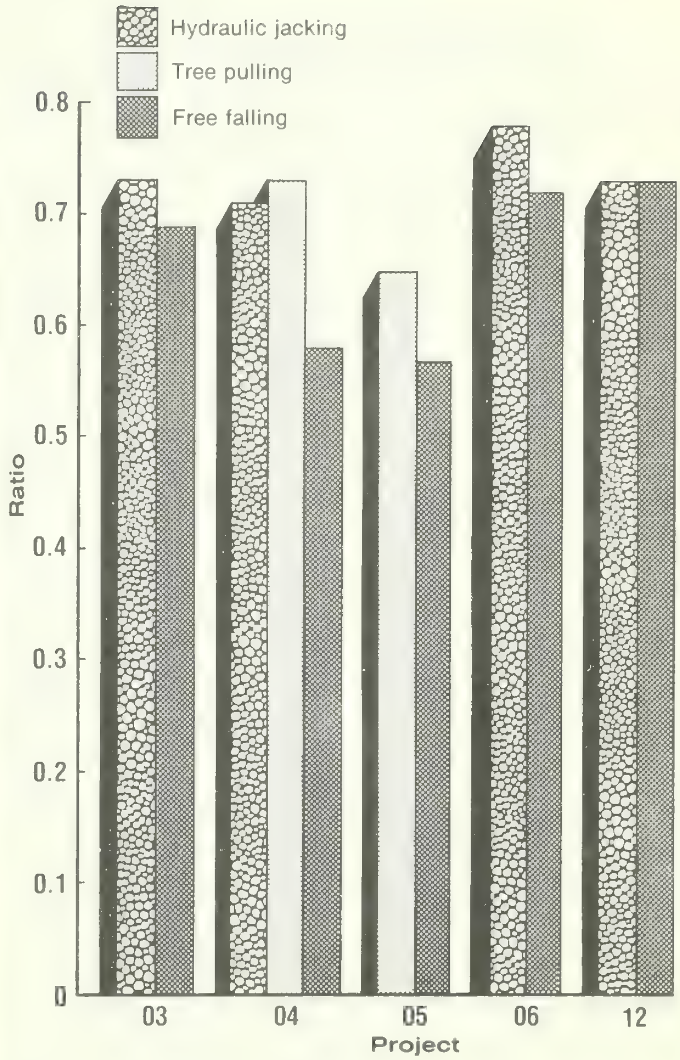


Figure 6.--Length of tree to the first break expressed as a ratio.

The location of the first break is important to the timber purchaser because it determines the number of logs of preferred length that can be cut (lengths and diameters that best fit manufacturing and marketing needs). Length to the first break is shown in figure 6 as a ratio of average length (height) to the first break over average tree height to a 6-inch top. Average length to the first break was determined by totaling lengths of all logs to the first break, and dividing this total by the number of trees. Average tree height was determined the same way.

In one sale, the first break occurred at the same point for both units. In the other sales, length to the first break occurred farther up the tree for units felled uphill. The increase in length ranged from 0 to 15 percent of average tree height, and averaged slightly under 8. In feet, the improvement ranged from 2 to 22 and averaged 12. Statistically analyzed, these values indicate that the differences are significant.

For scaled sales, where the purchaser pays only for logs brought out of the woods, there is no great incentive to reduce breakage. What a purchaser really wants are preferred log lengths.

Figure 7 indicates that more logs of preferred length were cut in the units felled uphill than in free-felled units. The fifth sale was omitted from this analysis because the operator changed log length requirements in one unit. This change prevented a comparison of preferred log lengths between units. For sales shown, the number of logs of preferred length increased from 5 to 17 percent and averaged slightly over 9 percent for the five units felled uphill. This increase in number of logs of preferred length is probably the most tangible benefit a purchaser receives from uphill falling. Again, analysis indicates the increase in logs of preferred length is real and not a chance occurrence.

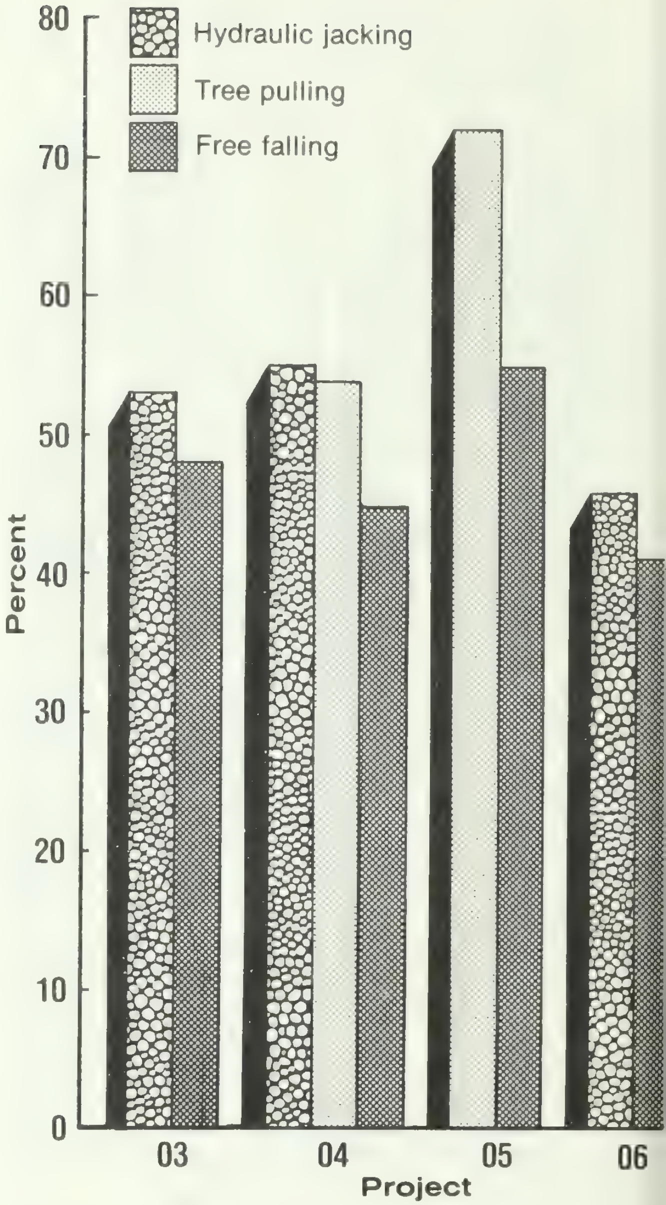


Figure 7.--Percent of logs in the preferred length.

Production Data

Falling and bucking costs were initially computed in dollars per thousand board feet. Data presented on this basis become obsolete when basic wage rates and fringe benefits increase. To keep the data as relevant as possible, we computed productivity in terms of the number of person-hours required to fall and buck 1,000 board feet. Since it was not possible to relate hours worked to species cut, production data are based on volume from all species in each unit.

Figure 8 shows that production rates on the free-felled units were invariably higher than on the units felled uphill.

Lower production in the jacked units was due to two factors--the requirement to fall uphill and to use jacks. A first reaction might be that these two factors are the same. Observations and data indicate, however, that falling uphill, even without jacking, is likely to be less productive than sidehill falling. Trees standing straight will rarely fall uphill without wedging, which takes time. Trees leaning out of the falling pattern must be jacked, and making the extra cuts needed for the jack seat and pumping the jacks takes time. Also, falling trees uphill requires cutters to spend more time moving their equipment up and down the hill. Bucking trees lying uphill is also more difficult and slower than bucking trees lying on the sidehill. Not only must the bucker continually move up and down the hill, but as a tree is being cut into logs, the uphill portion has a tendency to slip down and pinch the saw bar. This situation requires the bucker to spend more time using wedges to prevent pinching. All this adds up to lower production per person-hour and correspondingly higher costs per thousand board feet.

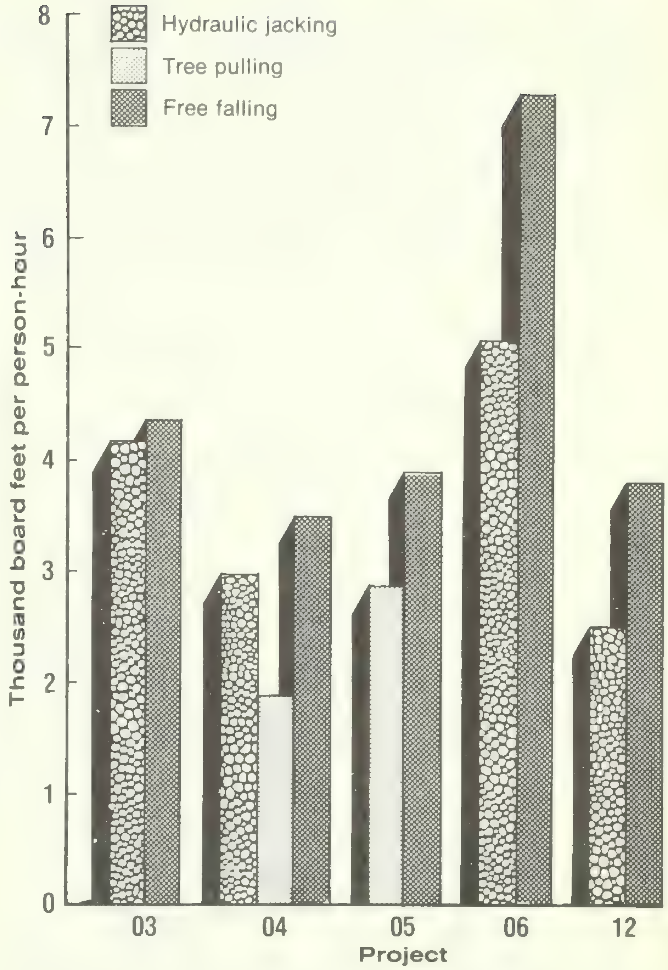


Figure 8.--Falling and bucking production by logging units.

Productivity is also lower in the tree-pulled units because additional crewmembers are needed to climb trees and operate machines. The project 04 crew averaged more volume cut per day in the tree-pulled and jacked units than they did in the free-fall unit. But dividing that volume by the person-hours required to produce it resulted in a lower volume per person-hour. Minor causes of lower productivity are changing the pulling line blocks and pulling the line down the hill. As for jacked trees, bucking trees after pulling is slower than free felling.

Comparisons of productivity cannot be made among the five sales because of differences in timber size and topography; however, some general observations about production rates may be made. Four of the five sales, projects 03, 04, 05, and 12, show productivity rates in the free-fall units that are reasonably close. Project 06 shows a rate for free falling that is more than twice that of project 04, and considerably higher than the others.

We believe the main reason for this high production rate on project 06 was the amount of single jacking (one person both falling and bucking). Ground, timber conditions, and cutters' abilities were not considered responsible for the differences between project 06 and the other projects. The slight loss in productivity from uphill falling in project 03 was probably because the unit had good timber on a relatively flat slope with little brush cover. The cutters could move freely on most of the ground and carry jacks more easily on the 35-percent slope than would have been possible on steep, brushy slopes; bucking was less of a problem too.

Project 04 illustrates the difference in falling and bucking productivity between jacking, tree pulling, and free falling similar timber on similar ground conditions. Figure 8 shows that the production rate for free falling is close to all other sales except project 06. Productivity in the jacked unit of project 04 dropped only slightly from the free-felled unit despite problems encountered in falling with jacks and bucking on steep slopes. Again, some single jacking was done in this unit, which probably helped maintain a good production rate. As expected, the tree-pulled unit showed a large drop in production. The four-person crew, although new to tree-pulling procedures, worked efficiently and usually had one or two trees rigged for pulling ahead of the cutters. Even so, the loss in productivity was almost half (46 percent) of the free-fall rate.

When depreciation, maintenance, and costs of operating tree-pulling equipment are added to the 46-percent loss in production, the costs of pulling trees in project 04 ($10.46 per thousand board feet) were double those for the free felled-unit ($5.22). Although high, this cost is considerably less than the rule-of-thumb cost of three times that of free falling.

In project 05, the difference in productivity between the tree-pulled and free-felled units is not great (fig. 8). Table 1 (page 2), however, shows that trees in the free-felled unit had an average d.b.h. of 45 inches compared with 48 inches in the pulled unit. This difference in d.b.h. resulted in an average gross volume per tree of 2,060 board feet in the free-fall unit and 3,750 board feet in the pulled unit. The larger tree volume in the pulled unit resulted in production only 24 percent less than the free-felled unit although only about half as many trees were cut per day in the pulled unit. To provide some insight to what the production loss might have been had tree sizes been comparable, the following adjustment was made.

The average gross tree volume in the pulled unit was adjusted down to the same level as in the free-felled unit. This tree volume was expanded (by the actual number of trees cut) to a new but smaller total volume. Dividing this total volume by the person-hours required to cut all the trees gave an adjusted productivity rate for the pulled unit. This new rate was 1,700 board feet per person-hour instead of the 2,900 shown in figure 8 and would result in 56 percent less production than the rate for free falling. Since only half the number of trees were cut per day in the pulled unit, this lower productivity appears reasonable. Although it may be questionable if the same number of hours would be required to cut smaller trees, we believe the adjusted rate based on trees of the same size more fairly represents tree-pulling productivity. Averaging the tree-pulling production rates from projects 04 and 05 results in a 51-percent loss.

Yarding productivity was also computed on the basis of volume per person-hour and is illustrated in figure 9. Only four projects are shown because project 05 required two landings in the free-fall unit for efficient logging. This, of course, reduced the average yarding distance in that unit and made comparison with other units impossible.

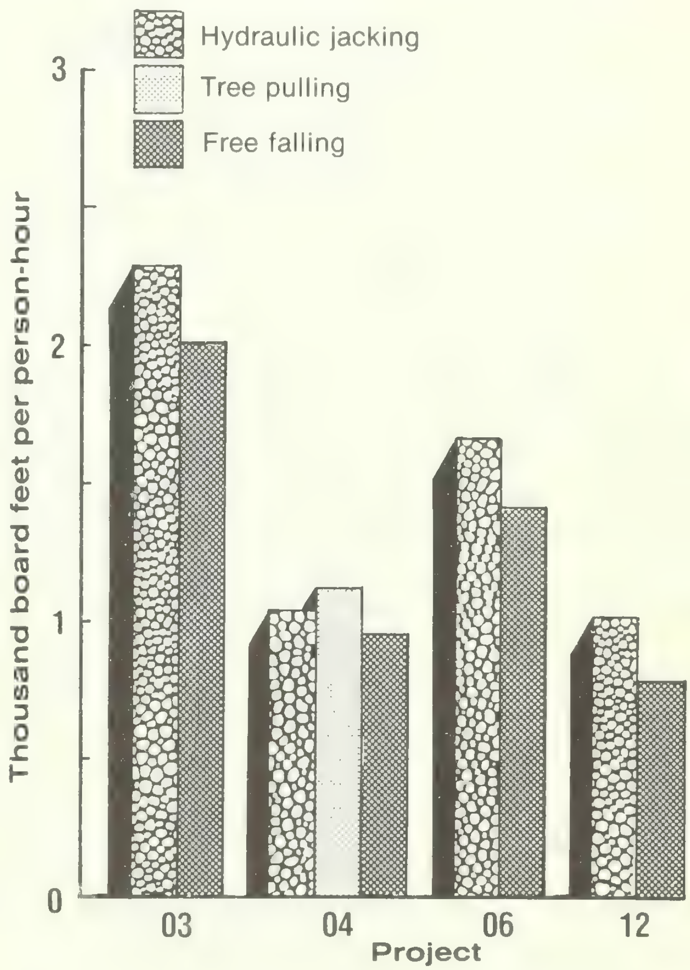


Figure 9.--Yarding production by falling units.

The hours worked by crews were recorded by occupation. This record was usually kept by the yarder engineer or the loader operator. Any delay time caused by yarder breakdown, line splicing, etc., was subtracted from total time on the job. Thus, the person-hours used for calculating productivity represent only time the yarder and crew were actually working.

Yarding productivity in the five units felled uphill was higher than in free-felled units. Data did not permit determining the factors responsible. But many loggers with experience on jacked or tree-pulled units claim that costs of YUM (yarding unmerchantable material) and clearing streams are lower when these methods are used. Any decrease in time required for YUM and stream cleanout would increase yarding production. In another sale, not included in these data but where stream cleanout time was recorded separately, considerably more time was spent clearing streams in the free-fall unit than in a unit felled uphill.

Statistical analyses of yarding productivity indicate that production per person-hour for the uphill-felled units was significantly higher than for free-felled units.

Loading efficiency was determined by the same procedure used for yarding. Figure 10 shows rates for the paired units. There seems to be little relationship between loading production and falling methods. In two of the uphill units, rates of loading were higher than in free-felled units; four uphill units had lower rates. Of the latter four, only one shows a large difference. Statistical analysis on loading production indicated that the differences in productivity were not significant. Therefore, we conclude that there is no improvement in loading productivity from uphill falling techniques.

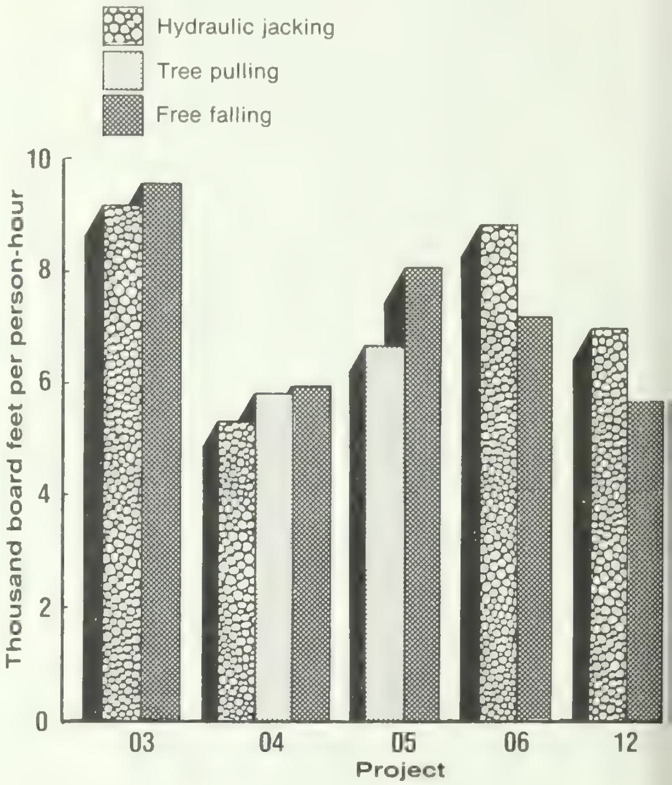


Figure 10.--Loading production.

Logging contractors and foresters who participated in the sales agreed with this conclusion. They failed to see how different falling methods could influence loading efficiency. The advantages of having slightly longer logs, slightly less log breakage, and perhaps fewer chunks were believed to be too small to affect loading productivity.

Application of Results

Expressing the costs of logging and truck-loading in thousands of board feet per person-hour provides a convenient method to compare costs but does not quantify monetary advantages of uphill falling. Two examples show that money could be saved through uphill falling under certain assumed but realistic conditions.

Costs for free falling and bucking were developed by applying an hourly wage rate to the person-hours.[3] Dividing total dollars spent for this work by the gross log volume from the cutters' records gave costs in dollars per thousand board feet. Costs for tree jacking were computed the same way, except that an additional $0.23 per thousand board feet was added for operation and depreciation of the jacks. Labor costs for tree pulling were calculated by the same rates, but estimating costs of the tree-pulling machine required a more detailed procedure. Based on estimates from reliable logging systems specialists, we assumed an initial cost of $15,000 for a pulling machine constructed of good used equipment. Calculating the depreciation of this machine with its rigging and operating costs gave a machine cost of $8.05 per hour. This rate was applied to the hours the machine was used to give total costs for the machine. Labor and machine costs were added, then divided by the cutters' volume to get a dollar cost per thousand board feet.

To pay for saws, $1.33 per hour was added to labor and equipment costs for all falling methods.

Costs for yarding and loading were developed the same way as for cutting. For each occupation, the appropriate hourly wage rate was applied to the hours worked and added to the hourly machine charges appropriate to the yarders and loaders used (see footnote 3). Before total costs were calculated, delay and breakdown times were subtracted so costs reflected only the time loader, yarder, and crew were actually productive. Labor and machine costs were totaled and the total divided by gross log scale volumes. This gave costs in dollars per thousand board feet, gross Scribner scale, for yarding and loading.

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[3] Cutters' hourly wage rate from the U.S. Department of the Interior, Bureau of Land Management, Timber Production Costs Schedule 20, 1977.

Value Comparisons

To illustrate how increased costs for uphill falling are more than offset by increased yarding productivity and increased timber volume, we compared costs and benefits under prescribed conditions.

We assumed a cruise volume of 60,000 board feet per acre, a stumpage value of $300 per thousand board feet, and a recovery volume 3 percent higher for tree jacking and 4 percent higher for tree pulling. Costs used for falling, bucking, and yarding are averages from the four paired units of this study. Since loading costs were not significantly different for units felled uphill or free felled, these were combined and averaged for all units.

Costs for falling, bucking, yarding, and loading a jacked unit and a free-felled unit show the following:

	Jacked unit	Free-felled unit
	(Dollars per thousand board feet, Scribner log scale)	
Falling and bucking	5.52	4.18
Yarding	14.68	16.51
Loading	4.15	4.15
Total	24.35	24.84

A unit jacked uphill produced a value higher than a comparable free-felled unit because greater volume was recovered. The difference was 1,800 board feet per acre, or 3 percent more than the cruise estimate of 60,000 feet.

	Jacked unit, 61,800 board feet per acre	Free-felled unit, 60,000 board feet per acre
	(Dollars per acre)	
Logging costs	1,504.83	1,490.40
Value at $300 per 1,000 board feet	18,540.00	18,000.00
Net value	17,035.17	16,509.60
Additional value	[4] 525.57	0

[4] $8.50 per 1,000 board feet.

We used the same method, assumptions, and costs to compare tree pulling with free falling.

Costs for falling, bucking, yarding, and loading in a pulled unit compare with costs for a free-felled unit as follows:

	Pulled unit	Free-felled unit
	(Dollars per thousand board feet, Scribner log scale)	
Falling and bucking	10.93	4.97
Yarding	14.68	16.51
Loading	4.15	4.15
Total	29.76	25.63

A pulled unit produced additional value over a free-felled unit because volume recovered was 2,400 board feet per acre, or 4 percent more than the cruise estimate of 60,000 board feet.

	Pulled unit, 62,400 board feet per acre	Free-felled unit, 60,000 board feet per acre
	(Dollars per acre)	
Logging costs	1,857.02	1,527.80
Value at $300 per 1,000 board feet	18,720.00	18,000.00
Net value	16,862.98	16,462.20
Additional value	[5] 400.78	0

[5] $6.42 per 1,000 board feet.

Observed Benefits

At the outset of the study, operators actively engaged in jacking or tree pulling stated that they found both methods had numerous advantages over free falling. Published reports in trade journals have claimed such advantages as less damage to roads, lower costs for clearing streams, lower yarding costs, greater production at mills, safer working conditions, and less tree breakage.

Not all these advantages were directly measured in the study, but some were observed and are described below.

Breakage on Roads

Roads, particularly at the bottom of cutting units, can cause substantial breakage during free falling. Since the larger limbs of most trees grow on the downhill or sunlit side of the slope, the trees usually lean in that direction. If the cutting unit has a road and the cutters start from it, many of the first trees cut fall either on the road or the bank (fig. 11).

Figure 11.--Trees free felled beside a road.

Figure 12 shows a jacked unit with a road at the bottom. Here, the trees at the edge of the road have been felled uphill and away from the road by use of jacks. Breakage in this area of the unit was almost nonexistent. In addition to savings on breakage, road maintenance costs are substantially lower since heavy equipment is not required to remove chunks and tops from the road as in a free-fall unit.

Figure 12.--Trees jacked beside a road.

Costs of Clearing Streams

A large amount of breakage can accumulate in a steep-sided stream after free falling; much of it is too big to remove by hand and must be pulled out by a yarder. In another study with two similar cutting units, each having about the same length of stream, the logger recorded time spent in clearing the streams. Hours of labor were 41 percent less in the unit felled uphill. Although these data are not part of this report, they are indications of savings that can be achieved in clearing streams and probably in reducing yarding costs.

Safety

Safety of workers falling trees uphill is a controversial subject, even among fallers. Pulling trees uphill with a cable should be one of the safest ways to fall timber because the cutters have time to retreat to a safe place before signaling the machine operator to pull a tree over. In the jacking method, if jacks are provided with long hoses (100 feet, for instance), cutters could be a considerable distance from a tree when it falls. With either procedure, the workers have time to avoid the falling tree and falling limbs. Unfortunately, in actual practice these procedures are not regularly used, especially in jacking. Most hydraulic jacks have a 10-foot hose as standard equipment. Rarely does a cutter purchase additional lengths of hose to allow working a greater distance from the tree. Many cutters prefer to stay close to the stump because, by moving around it, they can more easily avoid a tree that does not fall in the planned direction. Also, many cutters are concerned about production and sometimes are still cutting on a tree while final jacking is in progress. Cutters in a tree-pulling operation, too, sometimes will cut wood as the tree is pulled over.

Cutters who have not jacked or pulled trees on a regular basis often express fear of working beneath felled or bucked timber and cite safety laws. Timber felled uphill, however, is not as prone to roll downhill as is timber felled across a hillside. It lies in an uphill direction (fig. 13) and is not aligned parallel to the contours. Observations during this study indicated that uphill tree pulling or jacking, properly practiced, should be as safe as free falling. Fallers who regularly fall trees uphill say they feel as safe or safer than when they were free falling trees.

Figure 13.--Trees felled uphill.

Summary and Conclusion

n five timber sales in west-side old-rowth Douglas-fir, contract specifi-ations required one cutting unit to e felled uphill, using, when neces-ary, hydraulic jacks or a tree-ulling machine. Timber on the other nit was to be felled by the conven-ional or free-fall method. Yarding nd loading equipment, methods, and rew were to be the same in both units. ecords were kept on the falling and ucking, yarding, and loading opera-ions for each unit in each sale.

ata compiled from the falling and ucking phase indicated that total reakage was less, and tree utiliza-ion, log length to the first break, nd percent of preferred log lengths ere increased on units logged uphill. roductivity in terms of thousand oard feet felled and bucked per erson-hour, however, was decreased by bout 18 percent when trees were acked and 51 percent when they were ulled. When this loss of productivity as converted to dollars per thousand oard feet, falling and bucking costs ere increased 32 percent for jacking nd 120 percent for pulling.

n these same uphill units, yarding roductivity increased about 10 ercent on the basis of a thousand oard feet per person-hour; costs, in ollars per thousand board feet, ecreased about 11 percent. Loading roduction and costs were not affected y falling methods.

Data from this study applied to representative timber values and volumes indicate that jacking or pulling trees uphill instead of free falling them can result in an additional value of $8.50 and $6.42 per thousand board feet, respectively. This increase in value can be achieved despite an increase in costs of falling and bucking uphill. Increased cutting costs are offset by reduced yarding costs plus a saving of timber through reduced breakage.

Other advantages of uphill falling, which either are impossible to measure or were omitted from this particular study, include protection of water quality and fish habitat, being able to harvest in environmentally sensitive areas, reduced costs of maintaining roads, and increased production and values of end products at mills.

From these five timber sales, we conclude that falling old-growth Douglas-fir uphill benefits the public agencies that sell timber and the industry that harvests and processes that timber.

Metric Equivalents

When you know	multiply by	to find
inches	2.540	centimeters
feet	0.305	meters
acres	0.4	hectares

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1971. Uphill felling. Loggers Handb. 31:8-11, 104. Pac. Logging Congr., 217 Am. Bank Build., Portland, Oreg.

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Five timber sales were made in old-growth Douglas-fir with matched cutting units. On one unit of each sale uphill falling by either hydraulic jacks or tree-pulling machine was required; on the other unit free falling was required. Logging equipment and methods were the same in each unit. Uphill falling produced a larger volume of timber at less cost than free falling because breakage was less.

KEYWORDS: Felling operations, old-growth stands, Douglas-fir, *Pseudotsuga menziesii*.

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ABSTRACT

This paper documents current knowledge on interactions of livestock and fish habitat. Included are discussions of incompatibility and compatibility between livestock grazing and fisheries, present management guidelines, information needed for problem solving, information available for problem solving, and future research needs.

KEYWORDS: Livestock grazing, range management, fish habitat, riparian ecosystems.

USDA FOREST SERVICE
General Technical Report PNW-124

INFLUENCE OF FOREST AND RANGELAND MANAGEMENT ON ANADROMOUS FISH HABITAT IN WESTERN NORTH AMERICA

William R. Meehan, Technical Editor

7. Effects of Livestock Grazing

WILLIAM S. PLATTS

Intermountain Forest and Range Experiment Station
Boise, Idaho

1981

PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION
Forest Service, U.S. Department of Agriculture, Portland, Oregon

PREFACE

This is one of a series of publications summarizing knowledge about the influences of forest and rangeland management on anadromous fish habitat in Western North America. This paper addresses the effects of mining on anadromous fish habitat. Our intent is to provide managers and users of the forests and rangelands of Western North America with the most complete information available for estimating the consequences of various management alternatives.

In this series of papers, we summarize published and unpublished reports and data as well as observations of resource scientists and managers. These compilations should be valuable to resource managers in planning uses of forest and rangeland resources, and to scientists in planning future research. The extensive lists of references serve as a bibliography on forest and rangeland resources and their uses.

Previous publications in this series include:

1. "Habitat requirements of anadromous salmonids," by D. W. Reiser and T. C. Bjornn.

2. "Impacts of natural events," by Douglas N. Swanston.

4. "Planning forest roads to protect salmonid habitat," by Carlton S. Yee and Terry D. Roelofs.

11. "Processing mills and camps," by Donald S. Schmiege.

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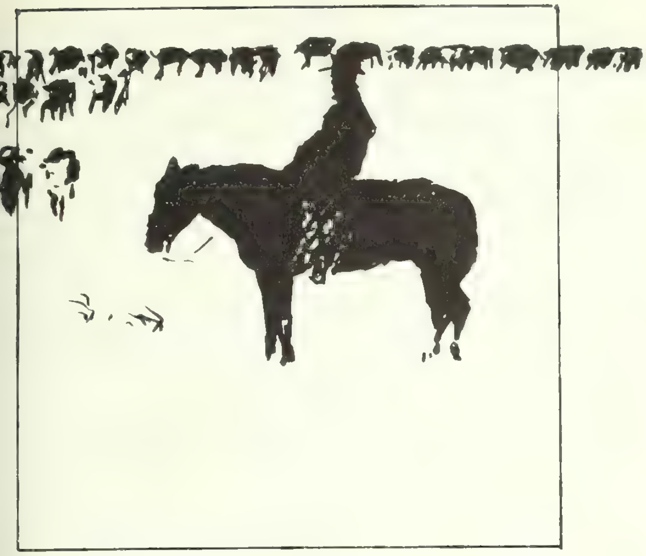
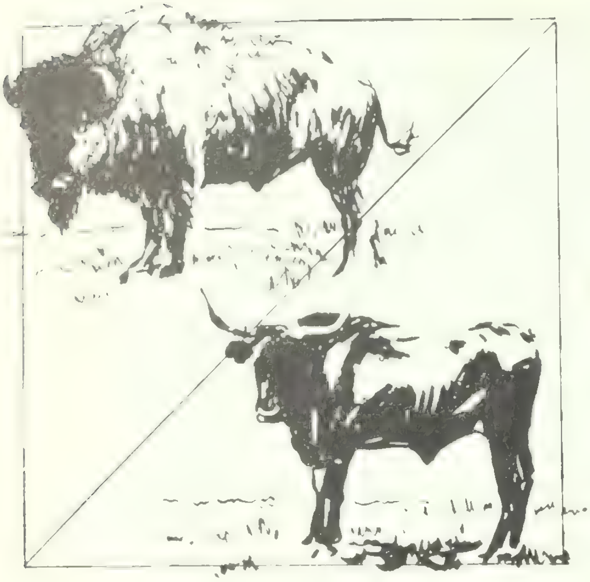


INTRODUCTION

Range was originally thought of as land for livestock use, but today, rangelands are managed for many other uses as well. The USDA Forest Service (1972) defines range as an ecosystem complex that contains the native and natural grasslands and pastures of the 50 States and Puerto Rico. This definition includes streams and their riparian environments, as well as forest communities suitable for grazing by livestock. Streams and adjacent habitats are the most productive ecosystems in rangelands. Livestock concentrate along these streamside zones (Holscher and Woolford 1953), and this excessive use has caused many environmental problems.

The USDA Forest Service definition of range increases the importance of range managers' understanding all range uses and how they relate to maintaining high-producing aquatic environments. Blaisdell et al. (1970) suggested that this definition of range insures that certain lands will not be ignored or mismanaged. They also pointed out that livestock production is but one of many range functions. Problems associated with management of riparian and aquatic environments must be solved, however, before these lands can be used for grazing without sacrificing associated resource values.

The forest range environment includes 1.2 billion acres in the United States. Sixty-nine percent of this rangeland was grazed by livestock in 1970, furnishing 213 million animal unit months of forage. Much of this rangeland has become depleted of natural and desirable vegetation, affecting runoff and adversely altering sediment recruitment and transport. Even though livestock use on western ranges has passed the 100-year mark, the effects of grazing on aquatic resources are just beginning to be understood. Research has not fully identified these problems, described their magnitude, or provided methods for their solution. As a result, resource managers have few data to assist them in correcting problems when they become apparent.



GRAZING HISTORY

Several publications provide a good historical background on the use of public ranges for livestock production (U.S. Senate 1936; Anderson and Harris 1973; Parsell 1973; Adams 1975; Meehan and Platts 1978.1/ 2/ Following is a brief summary.

Before the influx of Europeans into the Western United States, natural ecosystems existed in which wild ungulates usually grazed within the range's carrying capacity. If forage produced by a given range suddenly became scarce or nonexistent, wild grazing animals either migrated to more favorable ranges or sustained a mortality that brought the herds into balance with range capacity.

Soon after this country was settled, the possiblity of using the vast rangelands for livestock production was recognized, and since 1895 the number of cattle on western ranges and pastures has increased continually (see footnote 2).

Where the ranges were heavily stocked and livestock confined within barriers, changes in vegetation took place. Livestock trampled and compacted the soil, and the high-quality, fibrous-rooted plants gradually gave way to shallow-rooted annual species or taprooted forbs or shrubs that could exist on areas with lowered water tables. As soil compacted and favorable ground cover diminished, infiltration of water into deep soils lessened and surface runoff increased (Johnston 1962, Tromble et al. 1974, Heady 1975, Stoddart et al. 1975, Hibbert 1976). The accelerated rate of erosion had major effects on terrestrial and aquatic productivity. Rich topsoil was lost by the erosive action of wind and water, and the quality of streams receiving the eroded material was reduced. In addition, fine sediment smothered the spawning and rearing habitats of fish.

As the livestock industry grew through the 19th century and into the mid-1930's, the number of animals occupying the available range increased far beyond its carrying capacity. Serious concern about overgrazing of National Forest lands developed in the late 1920's. The situation became so critical by the mid-1930's that Congress enacted the Taylor Grazing Act in 1934 to reverse the trend on the remaining rangeland in the public domain and to help stabilize the livestock industry. Little attempt was made to regulate grazing, however, and detrimental effects continued to occur.

1/Unpublished report, "Effects of livestock grazing on wildlife, watershed, recreation and other resource values in Nevada," U.S. Dep. Int., Bur. Land Manage. Eval. Rep., 96 p. Washington, D.C. 1975.

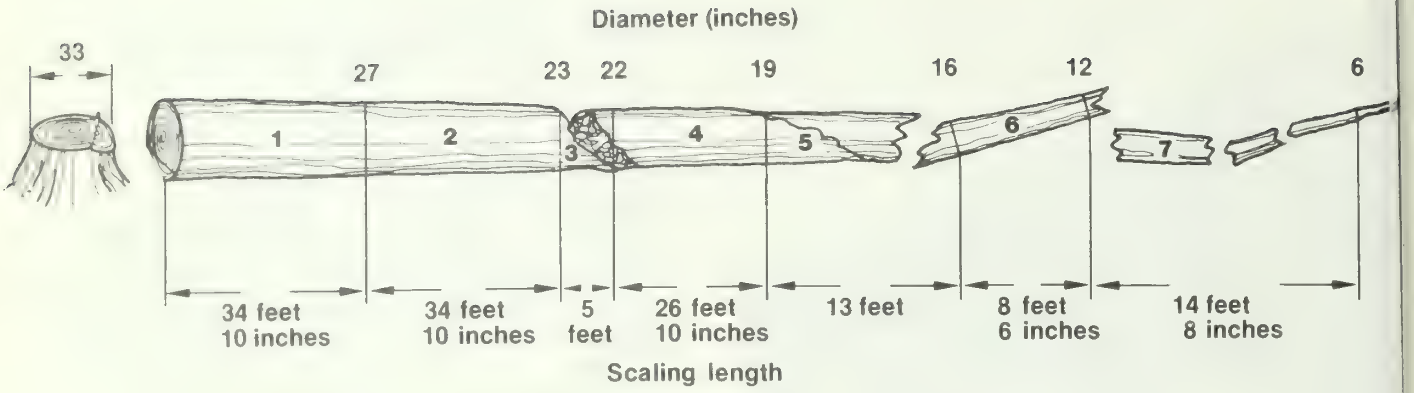
2/Unpublished report, "Effects of livestock grazing and the livestock industry on wildlife," by F. H. Wagner. Paper presented at symposium on livestock interactions with wildlife, fish, and their environments, Sparks, Nev., May 1977. On file at Univ. Calif., Davis.

By the mid-1960's, management by allotment had become an accepted practice, and this essentially is the practice today. Public awareness of environmental quality--including that of rangelands--brought into clearer focus the original goals of the Taylor Act. New approaches to range management were being considered during this period, such as those described by Johnson (1965) and Hormay (1970), which demonstrated that rest-rotation grazing can benefit range conditions. Livestock grazing studies were still focused on impacts on forage and physical characteristics of watersheds; influences of grazing on the aquatic ecosystem were still not given adequate attention. Also during this period, what was formerly sheep range was rapidly being converted to cattle range, placing more stress on riparian habitats.

In the 1970's, the importance of riparian vegetation to wildlife was becoming apparent in the literature (Patton 1977). Fishery biologists, however, were not well informed on grazing problems and their contribution to the understanding of land managers during this period was inconsequential. Today, decision-makers and fishery biologists see the need for better management of streamside zones, and scientists are undertaking studies of the interactions between livestock and fisheries. These trends are encouraging and will lead to better management of livestock and the aquatic habitat.

ENVIRONMENTAL CONCERNS

Recent, well-publicized events demonstrate the frustations land managers and scientists have experienced in dealing with complex range-management problems and the necessity of making decisions based on limited data (Miller 1972). The Natural Resources Defense Council in a 1973 suit questioned the adequacy of a USDI Bureau of Land Management (BLM) Environmental Impact Statement, "Livestock Grazing Management of National Resource Lands," to protect the environment. In the 1974 settlement of that suit, the BLM agreed to complete more than 200 separate environmental impact statements for livestock grazing on public lands in the West.



Segment 1: Coded 1, bucked log
Segment 2: Coded 1, bucked log
Segment 3: Coded 3, cull break
Segment 4: Coded 1, bucked log
Segment 5: Coded 2, sound break
Segment 6: Coded 1, bucked log
Segment 7: Coded 4, top break
The remaining segment is beyond the 6-inch top and was not measured.

Figure 3.--Codes by segment.

After these records were keypunched, a computer-edit program identified coding and recording errors which were then corrected. Other computer programs produced lists by tree, log, and breakage. Further analysis of variables was made possible by separating tree type, segment type, falling method, and species.

For statistical analysis, a randomized complete block design was used in which blocks were the entire sale areas and falling methods were the treatments within blocks. Because only one sale area provided three cutting units, four of the five blocks used only two falling methods.

Analysis of variance was used to test the one important contrast among falling methods. This compared uphill falling (both jacking and pulling) with free falling. Results showed uphill falling differed significantly from free falling in all variables tested, except loading productivity.

Results

Breakage Data

All breakage data in this report are from Douglas-fir trees 24 inches or more d.i.b. (diameter inside bark) at the stump. Data for the small understory trees were not included because initial analysis indicated that data from these trees distorted the results. Including data from hundreds of small trees reduced average tree height and length to the first break but contributed nothing to the breakage volume. Deleting small trees provided a more accurate picture of breakage in trees of sizes that concern both timber sellers and purchasers.

Total breakage (including sound, cull, and top) was reduced in units felled uphill compared with free-felled units in all sales except the South Susan Ridge (project 12). The difference in volume lost to breakage ranged from 2 percent to over 5 percent (table 2 and fig. 4). The average reduction in breakage for the five units felled uphill was 3 percent.

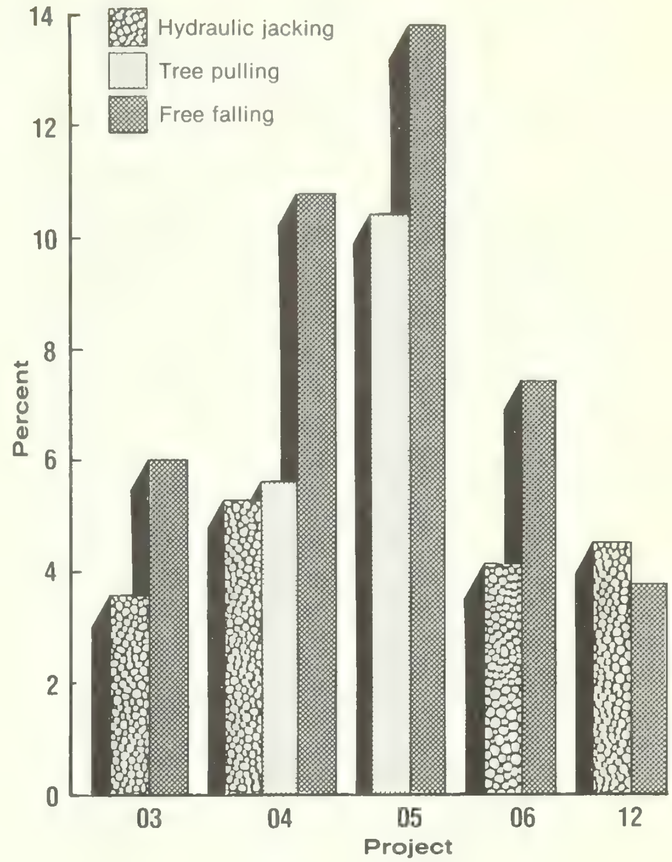


Figure 4.--Percent of cubic volume of tree lost in breakage.

Table 2--Percent of cubic volume lost, by type of breakage

Project	Sale name	Cutting unit[1]	Breakage				
			Sound	Cull	Top	Total	Difference
			- - - - - - - - - Percent - - - - - - - - -				
03	Loop Hope	FF	3.9	0.3	1.8	6.0	
		HJ	2.5	.1	1.0	3.6	2.4
04	Three Way	FF	7.4	1.3	2.1	10.8	
		TP	3.4	.4	1.8	5.6	5.2
		HJ	3.0	.9	1.4	5.3	5.5
05	Hobbit	FF	5.1	6.1	2.6	13.8	
		TP	3.7	6.1	.6	10.4	3.4
06	Trout Creek Hill	FF	2.7	2.0	1.7	6.4	
		HJ	2.2	.4	1.5	4.1	2.3
12	South Susan Ridge	FF	2.2	.3	1.3	3.8	
		HJ	3.1	.4	1.0	4.5	-.7

[1]FF = free or conventional falling; HJ = hydraulic jacking; TP = tree pulling.

Most of the rangelands were overgrazed during the past 85 years, so emphasis in present management is mainly on protection and improvement of plant cover. Today's range-management guidelines are just beginning to call for different management strategies for different habitat types; the guidelines of the past covered only broad combinations of lands that mixed the riparian zones with the upland zones. Land managers have often failed to recognize that streamside environments are different from other terrestrial systems and so need specialized management. The stream, the riparian environment, and adjacent upland environments each require different management strategies. For example, a broad riparian zone in a wet meadow has a different influence on a stream than a narrow riparian zone in a sagebrush ecosystem.

The fact that scientists still differ in their interpretation of the effects of grazing strategies on streams and riparian habitats complicates resource management. These disagreements must be resolved, because more and more pressure is being brought on land managers to increase the production of all resources. Grazing land is continually being reduced; this conflicts with the projected needs for an additional 70 million acres of range within the next 25 years to meet the demands for red meat (Council for Agricultural Science and Technology 1974). The increasing demand for energy development, recreation, and high-quality water will conflict with the demand for red meat--unless management can be more effective.

The solution to the environmental issue is certainly not to argue whether or not livestock grazing degrades riparian and aquatic systems, but to identify and develop grazing systems that are compatible with fishery and riparian habitats. In an extensive literature review, Meehan and Platts (1978) were unable to identify any widely used grazing strategy compatible with the environmental needs of aquatic ecosystems. The task of modifying existing grazing strategies or developing new ones that are environmentally compatible will be difficult. The problem becomes more complex when related range-management practices other than grazing alter streams and streamside environments. These include fertilization, irrigation, wetland drainage, brush control, debris disposal, control of undesirable forbs, mechanical soil treatments, seeding, prescribed burning, rodent control, insect and disease control, water development, fences, and timber thinning.

Scientists and land managers realize that solutions to grazing problems are not easily found. No single discipline possesses the skills and knowledge to solve all of the problems. Past studies have identified many problems and offer some guidance, but more studies are needed to develop a better understanding of the relation of grazing to fisheries. Agencies responsible for management of streamside environments have not adequately considered the influence of livestock grazing. Not all of the answers can be found right away. Persuading land managers to recognize and implement management practices that protect streams and their riparian environments will be difficult.

Most grazing systems currently in use are based on grazing selected pastures, with certain types and timing of grazing or nongrazing recurring at yearly intervals. The systems vary depending on the livestock operation and on the type and condition of the rangeland. Five grazing systems have come into common usage, which improve distribution of livestock and enhance plant growth and vigor.

In the season-long grazing system, selected pastures are used throughout the grazing season or any part of the year that grazing is feasible. Handling and movement of livestock are minimized, and the least investment of money is required. Past problems with this system have included the concentration of animals at favored locations (especially in riparian ecosystems); not all the herbage was adequately used, and more desirable forage plants were often overused, creating undesirable changes in range forage. This type of management can disperse livestock over more of the stream bottomlands than some of the crowding techniques such as rest-rotation.

The system of rotation grazing breaks the range into selected pastures or units that are used for shorter periods with heavier stocking of animals, followed by a period of rest to allow the vegetation to recover. This system favors maintenance of existing plant species and reduces uneven grazing.

Deferred grazing calls for the delay of grazing on a selected pasture to allow plant reproduction and establishment.

Deferred-rotation grazing is a systematic rotation system that includes deferment of selected pastures from grazing for certain periods. The success of this system is based on the premise that the complete allotment will benefit from these short rests. Grazing is usually allowed on all portions of the allotment for at least part of each growing season.

Rest-rotation grazing allows complete rest on part of the pastures during certain years or entire growing seasons. In this system, the vegetation is closely cropped and a high trampling effect exists for a short period, which helps regeneration by planting seeds. A more uniform use of forage resources is provided through better livestock distribution. Recent studies, however, suggest that rest-rotation grazing may concentrate animals on streambanks, resulting in overuse of riparian vegetation such as willow (*Salix* spp.)[6/]

[6/] Speech, "Rest-rotation grazing - a bummer," by W. R. Meiners. Presented to Soc. Range Manage., 27th Annual Meeting, Tucson, Arizona, 1974.

LIVESTOCK AND AQUATIC HABITATS

Streams have been subjected to damaging events since the time they were formed--damage from such natural events as glaciation, floods, temperature changes, fire, droughts, and--more recently--by human occupation of streambanks and use of streams and their surroundings for mining, timber harvest, livestock grazing, road construction, recreation, and sewage and waste disposal.

Livestock grazing can affect all four components of the aquatic system: streamside vegetation; stream channel morphology; shape, quality, and quantity of the water column; and structure of the soil portion of the streambank. Livestock grazing can cause annual micro-changes in the environment that can accumulate over many decades. These subtle changes are difficult to detect, whereas environmental changes from such sudden catastrophies as flood damage are usually readily observable and measurable. Whether a stream has suffered a catastrophic event or a long series of small annual events, the results for fish can be the same. The stream and its fisheries have been damaged and, even when stress is relieved, recovery may take years.

Effects of livestock grazing on fish and the aquatic environment have been listed by Armour (1977), Meehan and Platts (1978), and Platts (1978a, 1978b, 1978c). These papers are summarized in the next section, and additional effects of grazing are discussed.

STREAMBANKS

Streambanks bordering small streams (of stream order less than 6) provide the habitat edge needed to maintain high densities of fish. Fish often adapt to this habitat edge because stable and well-vegetated streambanks provide cover, control water velocities and temperatures, and supply terrestrial foods. The condition of the streambank often governs water depths and velocities the fish must live in. Stable streambanks are necessary to the fish in small streams.

The sloughing and collapse of streambanks caused by improper livestock grazing is probably the greatest effect of livestock on fish populations. Streambanks erode because livestock congregate along streams for shade, succulent vegetation, and drinking water. Elimination of vegetation and caving of overhanging streambanks by livestock are among the principal factors contributing to the decline of native trout in western streams (Behnke and Zarn 1976, Behnke 1977). Winget and Reichert found that livestock grazing adjacent to selected Utah streams reduced bank stability 59 percent.[7] In other Utah studies, where livestock exclosures were used, streambank stability increased 100 to 740 percent (Berry and Goebel 1978).[8]

Marcuson (1977) found that an ungrazed portion of Rock Creek, Montana, had 2.5 times less channel erosion than an adjacent stream section that was grazed. Duff states that when livestock were introduced into an area that had been ungrazed for 4 years, a 14-percent decline occurred in streambank stability within 6 weeks after introduction of grazing (see footnote 8). Hayes (1978) concluded, however, that streambank degradation--during spring runoff--occurs more often and to a greater extent along an ungrazed streambank than along a grazed streambank.

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[7] Unpublished report, "Aquatic survey of selected streams with critical habitats on NRL affected by livestock and recreation," by R. Winget and M. Reichert. U.S. Dep. Inter., Bur. Land Manage., Utah State Office, Salt Lake City, 109 p.

[8] Unpublished report, "Livestock grazing impacts on aquatic habitat in Big Creek, Utah," by D. A. Duff. Paper presented at symposium on livestock interactions with wildlife, fish, and their environments, Sparks, Nev., May 1977. On file at Univ. Calif., Davis.

STREAMSIDE VEGETATION

In combination with undercut banks and streamside debris, streamside vegetation provides fish cover. Binns found cover highly significant in determining fish biomass in Wyoming streams.[9] Boussu (1954) increased trout biomass more than 200 percent by simulating natural cover in a South Dakota stream. When cover was eliminated, trout biomass decreased.

Habitat for terrestrial insects, which are an important part of fish diet, is provided by the streamside vegetation which also provides organic material for about 50 percent of the stream's nutrient energy (Cummins 1974). Detritus formed from terrestrial plants is a principal source of food for aquatic invertebrates and eventually for fish (Minshall 1967, Meehan et al. 1977). A change in the quantity and quality of detritus reaching the stream can result in a decline in numbers of the organisms that fish eat and in a disruption of the stream's ability to process organic matter (Cummins 1974; Vannote, in press).

Streamside vegetation shades streams and keeps water temperatures cool (Brown 1976). Stream temperature for trout should not exceed 65°F (18.3°C) and should be even lower during the critical spawning and incubation periods. In the West, streams from which riparian vegetation has been removed are often too warm in summer and too cold in winter.

Streamside vegetation protects streambanks by reducing erosive energy, by helping deposits build the streambank, and by protecting the streambank from damage by ice, logging debris, or animal trampling. Removal of vegetation exposes soil to erosion by rain or surface runoff.

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[9] Unpublished report, "Evaluation of habitat quality in Wyoming trout streams," by N. A. Binns. On file at Wyoming Fish and Game Department, 260 Buena Vista, Lander, Wyoming, 1974.

Improper livestock grazing can affect riparian environments by changing, reducing, or eliminating vegetation and by the actual elimination of riparian areas by increasing channel width, channel aggradation, or lowering of the water table. The most apparent effects on fish habitat are the reduction of shade and cover and resultant increases in stream temperature, changes in stream morphology, and the addition of sediment through bank degradation and off-site soil erosion.

Duff (see footnote 8) found that when cattle were introduced into an area that had not been grazed for 4 years, the riparian vegetation declined 35 percent to pre-rest conditions in 6 weeks. Lorz (1974) found no difference in fish populations in ungrazed as compared with grazed sections of the Deschutes River, Oregon, when dense willow cover was on one or both banks.

Claire and Storch found that the willow canopy in an exclosed area provided 75 percent more shade to the stream than was found in the areas outside the exclosure that received year-round grazing.[10] Gunderson (1968) found streamside cover was 77 percent more abundant along an ungrazed section of Rock Creek, Montana, than along a grazed section. Stream temperatures increase in small headwater streams when riparian vegetation is removed and changes occur in the composition of fish communities in downstream waters (Vannote, in press).

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[10] Unpublished report, "Streamside management and livestock grazing: An objective look at the situation," by E. Claire and R. Storch. Paper presented at symposium on livestock interactions with wildlife, fish, and their environments, Sparks, Nev., May 1977. On file at Univ. Calif., Davis.

WATER QUALITY

Salmonids need water of high quality: it cannot be too warm or cold, too fertile or infertile, too fast or slow, or too high or low in dissolved gases. Water of acceptable quality, quantity, and regimen must first be present before the stream channel and streambank can form and contain it so that it fits the habitat needs of the fish. The quality of subsurface flows that enter streams is usually excellent; this new water needs only to be charged with certain gases and nutrients to sustain fish life. Most streams have high-quality water at their origin that deteriorates in downstream areas because of land uses.

As water quality decreases and the water becomes more turbid, fish must survive in a medium in which they have difficulty seeing or moving. Often a less turbid area is not available to them. Migrating fish may avoid turbid streams, but fish forced to remain in turbid waters may have trouble feeding, using oxygen, and reproducing.

Changes in water quality from range-management practices have long been recognized (Sartz and Tolstead 1974, Busby and Gifford 1978). Research to date has centered on water temperature, sediment accrual, and increased bacterial concentrations through addition of animal wastes to the streams; the true effects on living systems, however, have not been adequately determined.

TEMPERATURE

Claire and Storch noted that the average stream temperature of Oregon's Deschutes River through an exclosure that was ungrazed for 10 years was 12°F (6.7°C) lower than stream temperatures in grazed sections (see footnote 10). Removal of streamside vegetation can increase water temperatures in small headwater streams (Brown and Krygier 1967). The literature is uniform in predicting higher summer water temperatures with less streamside vegetation cover (Gibbons and Salo 1973).

SEDIMENT

Stream-channel sedimentation caused by soil erosion on millions of acres of rangeland has long been recognized as a major problem. Lusby (1970), studying the effects of grazing on watershed hydrology in Colorado, found that ungrazed watersheds produced only 71 to 76 percent as much sediment as did grazed watersheds. Moore estimated that rangelands accounted for 28 percent of the annual sediment production within the Environmental Protection Agency's Region 10 (excluding Alaska) and was second only to croplands in total production of sediment.[11/] He indicated that depleted plant cover and trampled soils are the most important factors contributing to erosion on grazed (particularly overstocked) lands. Duff (see footnote 8) found stream channel widths were 173 percent greater in grazed stream reaches of Big Creek, Utah, than in ungrazed stream reaches.

[11/] Unpublished report, "Livestock grazing and protection of water quality," by E. Moore. Environ. Prot. Agency, 1976, Seattle, Washington.

The general impact of sediment from rangelands on water quality has been documented (Engle 1972, Grant 1975). Although the effects of sediment on fish directly attributable to poor range-management practices have not been well documented, the general effects of sediment on fish and fish habitat are better known.

Several studies have demonstrated that rangeland abuse resulted in adverse hydrologic consequences including accelerated sediment transfer from the land to streams (Branson and Owen 1970, Branson et al. 1972, Gifford 1975). Studies that evaluate the effects of various grazing systems (e.g., rest-rotation and deferred-rotation) on in-stream sediment accrual are lacking.

Large quantities of fine sediment change the structure of aquatic communities, diminish total productivity, and decrease water permeability of channel materials used by fish for spawning (McNeil and Ahnell 1964, Cooper 1965). Saunders and Smith (1962) reported that increases in fine sediment decreased productivity of aquatic life by 37 percent; Cordone and Kelley (1961) found a decrease of 59 percent.

Fish need in-stream cover (rocks, rubble, gravel), especially during juvenile stages and winter conditions, and depend on aquatic and terrestrial invertebrates for food. Fine sediments filling the gravel-rubble interstices reduce the amount of protective cover and force young salmonids to live in surface waters where they are more exposed to severe winter conditions and predation. Large amounts of fine sediment kill fish embryos incubating in the streambed (Phillips et al. 1975) by impeding intergravel waterflow, thereby reducing oxygen supply to embryos and allowing toxic metabolic wastes to accumulate. Sedimentation in stream channels also depresses the food supply for fish by filling channel interstices and reducing the substrate's potential to produce food.

A considerable effort has been devoted to studying the effects of livestock wastes from feedlots, pastures, and wildlands on water quality (Morrison and Fair 1966, Robbins et al. 1972, Barker 1973). The primary consideration in these studies has been bacterial contamination. A program designed to evaluate the effectiveness of potential treatment and control measures for feedlot wastes has been underway for several years (Shuyler 1973). Summaries of studies and recommendations for treatment of feedlot wastes have been made by Porter et al. (1975) and Manges et al. (1975). A detailed bibliography on management of livestock waste has been prepared by Miner et al. (1972).

Kunkle and Meiman (1967 and 1968), Kunkle (1970), Darling and Coltharp (1973), and Skinner et al. (1974) attribute high concentrations of coliform bacteria in study streams to livestock grazing. Although livestock-caused bacterial concentrations do not directly affect suitability of habitat for fish, they are nonetheless important indicators of water quality and hence relate indirectly to fish habitat.

WATER QUANTITY

Livestock managers were generally unaware, in the early years of the industry, of the limits to which vegetation and soil could be stressed (Council for Agricultural Science and Technology 1974). These resources have only recently been afforded their full credit as controllers of water on the land (Croft 1953). Range practices can significantly affect water yield, peak stream discharge, stormflow runoff, and associated water quantity factors. Water management and rangeland management are thus closely interrelated.

Many studies show the effects of livestock grazing on runoff (Haynes and Neal 1943, Packer 1953, Leithead 1959, Liacos 1962, Rauzi and Hanson 1966, Lusby 1970, Sartz and Tolstead 1974, Smiens 1975). As grazing intensity increases, water yield as runoff increases. Soil compaction and consequent decrease in infiltration rate, as well as cover depletion, are the primary reasons.

Other studies have specifically demonstrated that infiltration rates decrease as grazing intensities increase (Coupland et al. 1960, Branson et al. 1962, Johnston 1962, Meeuwig 1965, Rauzi and Smith 1973, Smiens 1975).

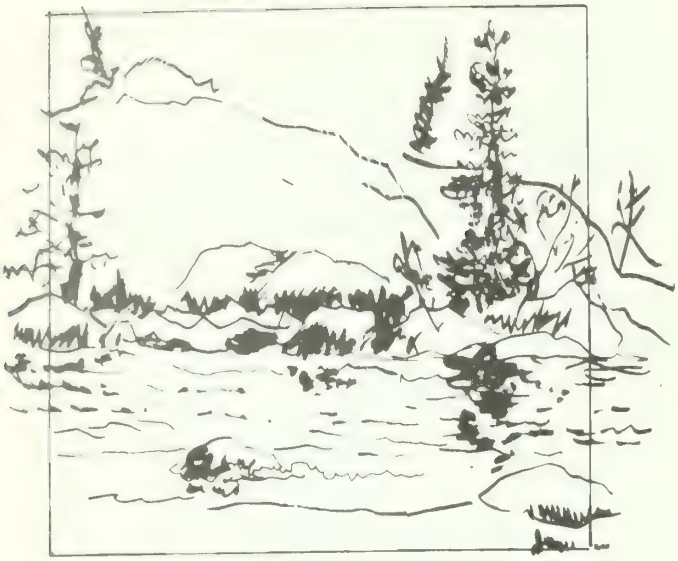
FISH POPULATIONS

The literature shows that streams modified by improper livestock grazing are wider and shallower than these streams would have been naturally. Generally, they have channels that contain more fine sediment, streambanks that are more unstable, banks that are less undercut, and higher water temperatures in summer than undisturbed streams. A recent detailed review of the literature (Meehan and Platts 1978), however, pointed out the lack of quantitative data in this field; nevertheless, most of the reported studies show decreases in fish productivity with increasing livestock use.

Three years after being fenced to exclude livestock, Otto Creek, Nebraska, improved from a nonproducer to a major producer of trout (Armour 1977). The stream width decreased, streambanks quickly stabilized, and water temperatures in summer were 2^{o} to 5^{o}F lower than before livestock exclusion. Claire and Storch (see footnote 10) found that over a 10-year period of nongrazing within an exclosure on the Deschutes River, Oregon, the fish population shifted from predominantly dace (Rhinichthys sp.) to rainbow trout (Salmo gairdneri Richardson).

Marcuson (1977) found that biomass of brown trout (S. trutta Linnaeus) per unit area within a nongrazed section of Rock Creek, Montana, was 340 percent higher than in an adjacent stream section that was heavily grazed. In the same stream, Gunderson (1968) found that trout were 27 to 400 percent more abundant in ungrazed than in grazed sections. Kennedy (1977) reported that trout numbers were 240 percent higher in ungrazed sections of an Oregon stream than in grazed sections. Duff found trout populations 360 percent higher in ungrazed stream reaches of Big Creek, Utah, than in grazed stream reaches (see footnote 8). Lorz (1974) reported that trout populations were about 350 percent higher in ungrazed sections of the Little Deschutes River, Oregon, than in grazed sections. These studies strongly suggest that improper livestock grazing decreases both quality and quantity of fish populations.

Kimball and Savage (1977) reported a 425-percent increase in fish populations in a section of Diamond Fork Creek, Utah, after livestock had been kept away for 4 years, and forage utilization was reduced 60 percent from past use, once grazing was resumed. The installation of structures for stream improvement and the planting of willows and grasses within the study area may also have contributed to the increase in number of fish collected. Fisheries apparently can benefit from improvements in present patterns of livestock management. Lorz (1974), Marcuson (1977), and Duff (see footnote 8), however, all reported reduced vegetation and more unstable streambanks in areas being grazed by the commonly used methods.



AVAILABLE GUIDELINES

Present management direction related to streams and streamside ecosystems varies among agencies and among divisions within agencies. Management direction is supplied to land-management agencies through laws, regulations, manuals, land-use plans, and allotment guides. This management direction generally requires protection of soil, water, and air. Agencies have recently been given additional guidance through Public Laws 92-500 and 95-217, which provide definite guidance for control of nonpoint-source pollution.

A livestock-fishery interaction symposium (see footnote 5) rated some of the most commonly used grazing strategies (table 1). Based on this analysis, present range-management guidelines are not commensurate with maintenance of high-quality fish habitat. The symposium proceedings lists goals for managers:

- Sufficient streamside vegetative canopy should be maintained to prevent unacceptable water temperatures.

Table 1--Condition of riparian-aquatic habitat resulting from various grazing strategies (see text footnote 5)

System	Condition of resulting riparian-aquatic habitat
Year-long grazing	Poor
Season-long grazing	Poor
Deferred grazing	Poor to fair
Rotation grazing	Poor to fair
Deferred-rotation grazing	Poor to fair
Rest-rotation grazing	Poor to variable[1/]
Short duration, high-intensity grazing	Variable[1/]
No grazing	Good to excellent

[1/] Resource damage, especially streambank cutting, within heavy-use units may not be repaired within the grazing cycle.

- Streambanks should be well vegetated to hold soil in place and to keep trampling damage by livestock to a minimum.

- Overhanging streamside vegetation (within 2 feet of stream surface) should be maintained to provide needed fish cover.

Range-management practices presently recommended for protecting, restoring, or enhancing fish and riparian habitats were listed as:

- Allow complete rest from livestock grazing to degraded riparian areas for as long as required to meet the above goals.

- Defer grazing on streamside areas to late fall when possible.

- Recognize specific needs of the different ecological units in ranges or pastures. For example, hillsides differ greatly from riparian areas in grazing suitability and potential for grazing damage, and managing these two habitats as a single unit is unrealistic.

- Improve off-stream distribution of livestock in areas bordering riparian zones.

- Allocate vegetative cover in the streamside zone for fish at the same time forage is allocated for livestock grazing.

A problem facing biologists attempting to evaluate the influences of different systems of livestock grazing is that methods must be developed to detect, within narrow limits, natural variation in streamside vegetation, in streambank and stream channel conditions, and in standing crops and community structure of fish. Combined effects of geology, climate, soil, vegetation, and water runoff often result in unstable stream conditions, even without grazing livestock. Natural variation is difficult to isolate because most aquatic sites have been modified by land uses for a long time, and recognizing what is and what is not "natural" is difficult.

Studies in Wyoming have associated environmental conditions with trout biomass (Wesche 1973, 1974). Biologists need, however, to develop better methodology to isolate and evaluate natural and artificial changes in aquatic components (Platts 1976). Workable guidelines will be difficult to develop until these problems are solved.

The USDA Forest Service has two research programs designed to further the knowledge of livestock effects on aquatic systems and assist in the preparation of better guidelines. One of these studies is being conducted in eastern Oregon by the Pacific Northwest Forest and Range Experiment Station[12/] and the second, by the Intermountain Forest and Range Experiment Station in central Idaho.[13/] These studies will quantitatively evaluate the effects of different types of livestock-grazing practices on aquatic and riparian systems. Other agencies are probably also conducting research on this problem.

[12/] Study plan, "The influence of grazing on riparian and aquatic habitats in the central Blue Mountains," by J. M. Skovlin and W. R. Meehan, USDA For. Serv., Pac. Northwest For. and Range Exp. Stn., Portland, Oreg., 1975.

[13/] Study plan, "The effects of livestock grazing in high mountain meadows on aquatic environments, streamside environments, and fisheries," USDA For. Serv., Intermt. For. and Range Exp. Stn., Boise, Idaho, 1975.

INFORMATION NEEDED

Studies that will provide resource managers with quantitative information upon which to base land-use planning decisions are needed on both the physical-chemical and biological aspects of the interrelation of livestock grazing and the aquatic habitat. Physical and chemical considerations include effects of livestock use of valley bottoms on water quality, stream channel morphology, streambed condition, and the riparian zone. Biological information is needed on impacts of livestock on standing crop and species diversity in populations of fish and benthic invertebrates, bacteriological aspects of water quality, and recreational and esthetic values in the use of the fishery and the aquatic and riparian ecosystems.

Advanced grazing systems have been used with the goal of enhancing the welfare of the range and production of livestock. Resource managers need to know how these grazing systems influence other resources including populations of anadromous and resident coldwater fish.

The broad research needs encompass a wide area: inventory, assessment, and classification; ecosystem dynamics; autecology and physiology of deciduous tree species; impacts of land-management practices; social and economic problems; and alternatives in riparian management.

Fishery biologists are confronted with the problem of determining how different types of grazing systems affect the various aquatic components and how changes in these components affect fish health and survival. Fishery research needs thus narrow down to seeking answers to these questions:

- Which of the existing grazing systems are most compatible with the fishery resource?
- What innovations are needed to make livestock grazing more compatible with fishery needs?
- Is one grazing strategy best suited for riparian areas?
- What is required and how long does it take for a stream altered by livestock grazing to return to natural conditions?
- What techniques are available or should be developed to reduce the recovery time for degraded streams?
- How much is fish production increased from improvement or protection from livestock grazing of streamside areas?
- If streams need to be protected by fences, what type of stream and how much of each stream should be fenced?
- How much vegetative canopy is needed on streambanks to prevent unacceptable stream temperatures?

- How do different classes of livestock affect the riparian environment?

- What are the first indicators that a stream is beginning to deteriorate or to improve from management of livestock?

- How much forage use can the different vegetative types and streambanks support without unacceptable changes?

- Is livestock grazing less damaging at some times of the year than at others?

Once these questions are answered, strategies for range management can be improved. The future demands that streams be as productive as possible in grazed areas and the first step is an effective research program to provide the needed answers.

SUMMARY AND DISCUSSION

Livestock grazing can affect all components of the aquatic system. Grazing can affect the streamside environment by changing, reducing, or eliminating vegetation bordering the stream. Channel morphology can be changed by accrual of sediment, alteration of channel substrate, disruption of the relation of pools to riffles, and widening of the channel. The water column can be altered by increasing water temperature, nutrients, suspended sediment, bacterial populations, and in the timing and volume of streamflow. Livestock can trample streambanks causing banks to slough off, creating false setback banks, and exposing banks to accelerated soil erosion.

Documenting and evaluating effects of these alterations are difficult, because nature causes similar alterations and effects. Fishery biologists are confronted with the problem of determining how different types of grazing systems affect the various aquatic components and how changes in these components affect fish health and survival. Whether a stream suffers a catastrophic degrading event or a long period of annual lesser events--such as grazing by livestock--the result for fish can be the same and recovery may take years.

Streams and streamside zones are most critical for multiple-use planning and offer the greatest challenge for proper management; stream habitats, therefore, should be identified as separate management units to receive intensified management. Land-management agencies responsible for managing livestock grazing must give adequate consideration to the influence of grazing on streams and streambanks. Land managers often fail to recognize stream ecosystems as separate systems in their management programs. This oversight occurs even though studies have demonstrated that practices that protect streambanks from damage also enhance the potential of riparian vegetation to support other resources (Gunderson 1968; Marcuson 1977; Duff (see footnote 8)).

Past management has allowed streamside environments to deteriorate, and land managers do not have the information they need to correct the problems. Fishery and range researchers must concentrate on providing such information to land managers, so that each riparian resource can be managed without infringing on other uses.

McGowan (1976) and Platts (1978c) doubt that present grazing strategies will solve the problems in the aquatic environment that grazing causes. If this assessment is valid, research is needed that does more than just evaluate present management systems. Scientists must conduct interdisciplinary research that will result in recommendations for new grazing strategies. When such strategies are available to the resource manager, rangeland decisions can be made with maximum consideration and understanding of the aquatic resource.

Improved livestock management will result in more stable streambanks and stream channels, reduction of soil erosion and consequently reduced stream sedimentation, improvement of streamside vegetative cover, improved water quality, and increased riparian forage and fish production. Improvement of streamside vegetation will also increase the abundance and diversity of terrestrial wildlife. Proper management of livestock will increase resource values and, in turn, economic benefits to all users. A short-term loss of forage for livestock may occur, when overused and degraded riparian communities are put under proper management, but increased forage production should ultimately be a result of improved resource management.

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Bird Exclosures for Branches and Whole Trees

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Contents

Abstract

Campbell, Robert W. Torolf R. Torgersen, Steven C. Forrest, and Lorna C. Youngs.
1981. Bird exclosures for branches and whole trees. USDA For. Serv. Gen. Tech. Rep. PNW 125, 10 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Two types of lightweight, portable bird exclosures are described. One is for individual branches or branch tips; the other is for whole trees up to 9 m tall. Several alternative configurations and uses of these exclosures are discussed.

Keywords: Birds, exclosures, defoliation damage, insect populations.

Introduction

Exclusion of selected groups of predators has sometimes been used to develop and test hypotheses about processes that determine population changes in forest-dwelling defoliators. Exclusion methods have included various sorts of barriers to keep predators away from the prey insects, structures that reduce the likelihood of contacts between predator and prey by modifying prey behavior, continuous trapping and removal of predators, and combinations of several methods (Campbell and Sloan 1977, Holmes et al. 1979, Smith and Lautenschlager 1979).

Lack of suitable exclosures has been a longstanding obstacle to empirical work on population dynamics of defoliators. Although many investigators have commented on the possible role or roles of avian predators in the population dynamics of forest-dwelling insects, few have used bird exclosures to provide empirical data. This is not surprising. Bird exclosures suitable for field studies have seldom been developed because of problems with cost of materials, weight, portability, and lengthy construction time. In this paper, we describe two kinds of bird exclosures that should help resolve these problems. One is for individual branches or branch tips up to 1 m long; the other is for whole trees up to 9 m tall.

Single-Branch Exclosures

In 1979, we experimented with single-branch bird exclosures as part of our continuing studies on the population dynamics of the western spruce budworm, *Choristoneura occidentalis* Freeman. For each population studied, budworm density and changes in that density can be inferred from the numerical patterns found in key portions of the crowns of host trees. We postulated that results derived from a series of single-branch bird exclosures in each of these key portions of the crown should yield data adequate for inferring the effects of avian predators on the population.

Frames for the exclosures are made of nominal ½-inch IPS, class 315 psi, polyvinylchloride (PVC) pipe. The top and bottom frames of a single-branch exclosure are made of four 1-m lengths of pipe joined by PVC elbow joints cemented with PVC adhesive primer. The uprights, ¾ m long, are nominal $\frac{3}{16}$-inch cold-rolled steel rods. The frame is covered with 1-cm X 2-cm polypropylene garden mesh attached to the frame with wire bag ties. Each branch exclosure assembly is held up by a wooden support 4 cm X 9 cm of the appropriate length (about 12- to 20-foot "2 X 4's") plus baling wire and stakes (fig. 1). In 1979, we placed 20 exclosures at about 2 m above ground and 20 at 4-5 m; in 1980, 60 cages were placed at about 2 m and 50 at 4-5 m.

To install exclosures, we first selected a branch, marked the appropriate cage height on a wooden support, and mounted an assembled exclosure there. The exclosure side opposite the support was left unsealed until after the exclosure had been placed around the branch. We used an 8.5-m aerial ladder mounted on a pickup truck for installing the exclosures that were 4-5 m above the ground.

About 1 worker-hour was required to assemble each exclosure. With the ladder truck, three people could install an average of about 20 exclosures per day. When necessary, we gained access to the branch inside an exclosure through a flap cut in the mesh which was reclosed with wire ties.

Whole-Tree Exclosures

Figure 1.—Single-branch exclosure installed 2 meters above ground.

None of the 40 exclosures used in 1979 appeared to have been damaged in any way during about 7 weeks of continuous use. For winter storage, the exclosures were removed from the supports, the steel rod uprights removed, and the assemblies collapsed.

We estimate the total cost in 1980 averaged $23.47 per completed branch exclosure ($1.82 for PVC pipe; $1.20 for PCV elbows; $1.20 for steel rods; $1.50 for polypropylene mesh; $5.00 for 2 X 4 support; $.75 for stakes and wire; $3.00 to lease the aerial ladder; and $9.00 for labor).

After the 1979 season, we designed and built a prototype portable, lightweight exclosure suitable for keeping birds away from a tree up to 9 m tall. During 1980, we built and installed 32 of these exclosures.

Each octagonal exclosure is built from 24 2-m X 3-m panels, made of lengths of PVC pipe, joined by PVC pipe T's cemented with PVC adhesive primer, and covered with polypropylene mesh. In the field, three of these panels are joined into a composite 2- X 9-m panel, or side, by tapping a removable 4-cm-long piece of PVC pipe (nipple) into adjacent pairs of T's. Mesh flaps are used to close the apertures between adjacent 2- X 3-m panels. For horizontal strength, the bottom 2- X 3-m panel has two intermediate crossbars, 1 m apart. Each upper panel has one intermediate crossbar.

Pairs of 2- X 9-m sides are joined along one edge by bailing wire. Two of these sets of double sides are then joined together and strengthened by wiring them to two 7.32-m wooden 2 X 4's (fig. 2). Before the assembled set of four sides is erected, guy wires are attached at each juncture between adjacent sides—one at 4.5 m, the other at 7.5 m. The four sides —which constitute half of an exclosure—are folded like an accordian and can easily be carried by four or five people (fig. 3).

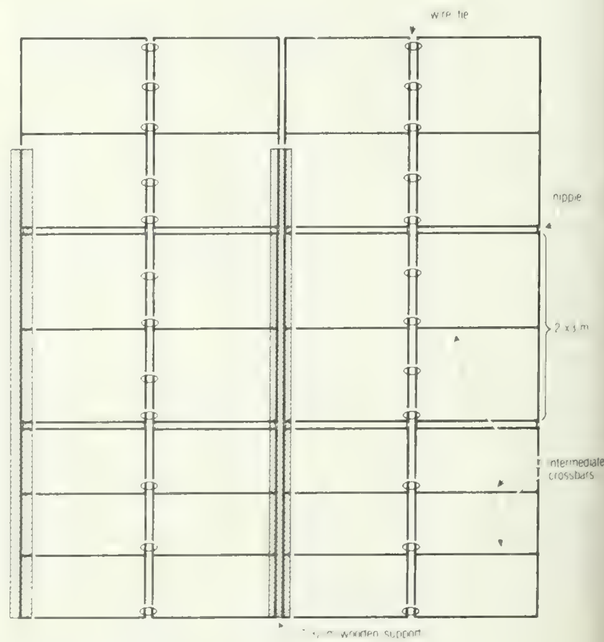

Figure 2.—Schematic view of a four-sided assembly used in construction of a whole-tree exclosure.

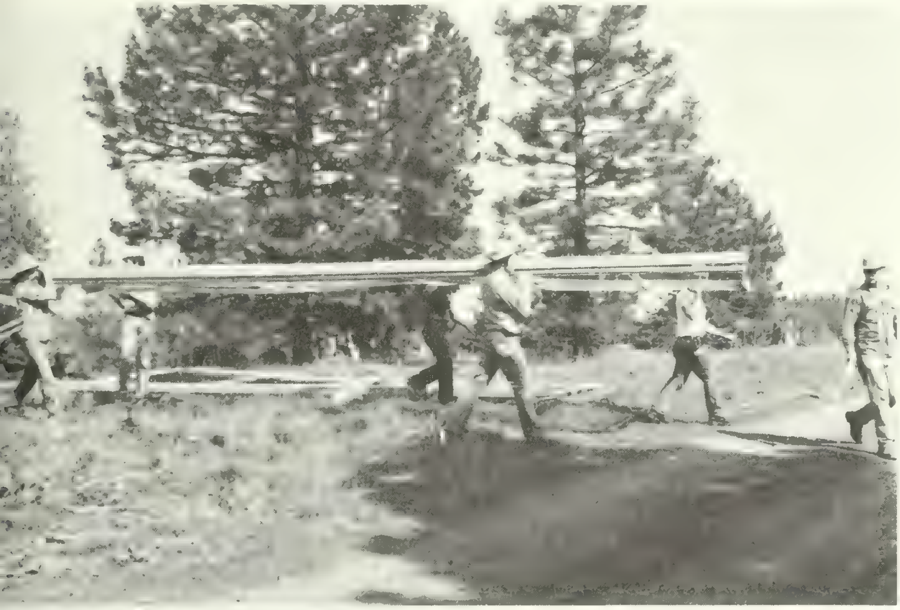

Figure 3.—Carrying an assembled set of four sides.

For erecting the exclosure, we used two aerial ladders or hydraulic lifts mounted on trucks (figs. 5, 7, and 9). Even with the 2 X 4's, the assembled 2- X 9-m sides are extremely flexible (fig. 4). Coordination is required between the aerial operators and the ground crew to erect, spread, guy, and tie together both of the four-sided assemblies that make up a complete exclosure (figs. 5-8). Finally, the aerial operators spread and tie down the polypropylene mesh top (fig. 9), and the exclosure is complete (fig. 10).

About 20 worker-hours are required to assemble the 24 2- X 3-m panels used in one whole-tree exclosure, and to attach the polypropylene mesh. In the field, three people can assemble the eight 2- X 9-m sides needed to build one whole-tree exclosure in about 1 hour. A seven-person crew working with two aerial lifts can install four whole-tree exclosures per 8-hour working day, if total travel time between set-ups does not exceed about 1 hour. Thus an average of 37 worker-hours is required to assemble and install one whole-tree exclosure.

We estimate the total cost in 1980 averaged $425.63 per completed whole-tree exclosure ($66.50 for PVC pipe; $24.00 for PVC pipe T's; $72.00 for polypropylene mesh; $28.00 for 2 X 4's; $3.00 for stakes and wire; $65.63 to lease two aerial lifts mounted on trucks; $166.50 for labor). During subsequent years, average seasonal costs per exclosure will drop, because we anticipate using these exclosures each field season for the next several years.

Figure 4.—Erecting a four-sided assembly; note rope to aerial operator.

Figure 5.—An erect four-sided assembly.

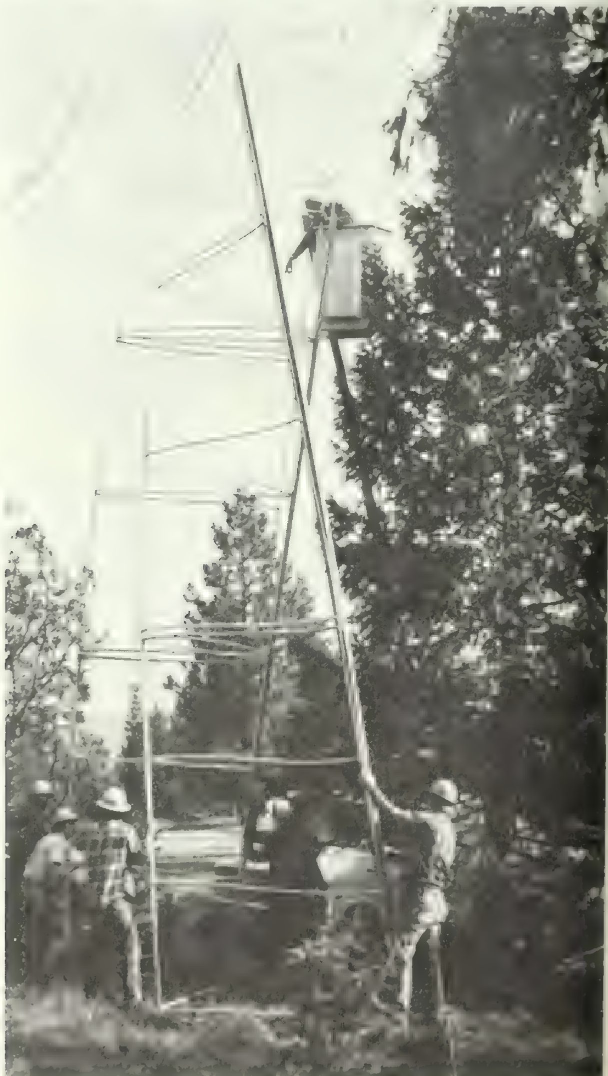

Figure 6.—Spreading the first half-exclosure.

Figure 7.—First half-exclosure in place.

Figure 8.—Spreading the second half.

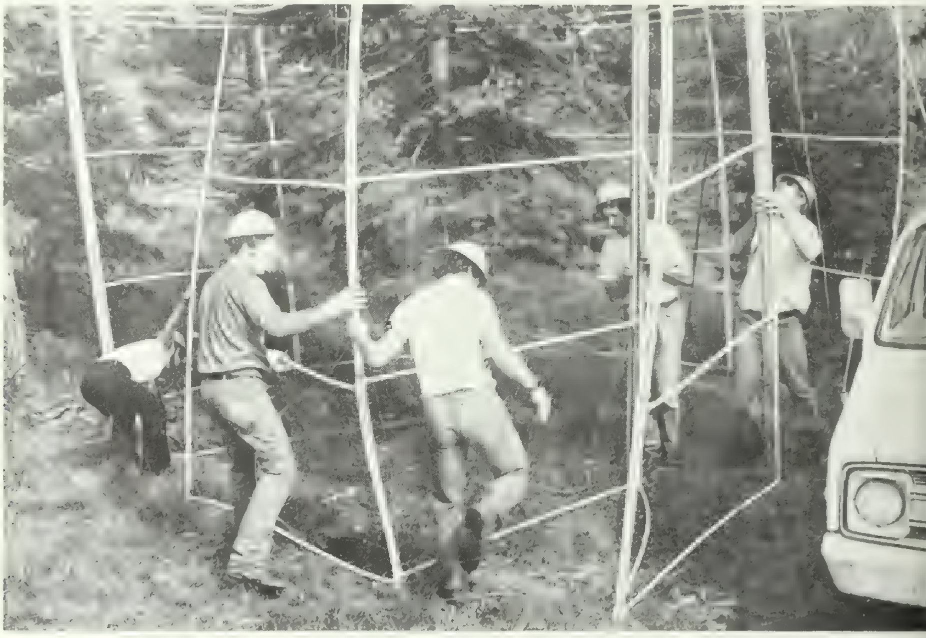

Figure 9.—Installing the top.

Figure 10.—A complete whole-tree exclosure. Note the second exclosure in the background.

Discussion

Because of their modular construction, the whole-tree exclosures described here can be modified in many ways. For example, the panels could easily be adapted to enclose a larger number of shorter trees. Similarly, a smaller sized mesh could be used to exclude flying invertebrates, such as parasites. The exclosures could also as readily serve as enclosures, depending on the objectives of the work in progress.

In conjunction with other techniques, such as barriers to prevent walking invertebrate predators from reaching host insects, the exclosures can be used to unravel the possibly confounding effects of two or more natural enemy guilds.

We designed these exclosures for use in the relatively open conifer forests that are characteristic of much of the interior West. We are confident, however, that they could also be modified for use in both hardwood forests and more dense stands.

We think it unlikely that the exclosures will result in substantial modifications in the microclimate within, because of the large mesh size. We intend to monitor the microclimate inside and outside several exclosures to resolve this question.

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Two types of lightweight, portable bird exclosures are described. One is for individual branches or branch tips; the other is for whole trees up to 9 m tall. Several alternative configurations and uses of these exclosures are discussed.

Keywords: Birds, exclosures, defoliation damage, insect populations.

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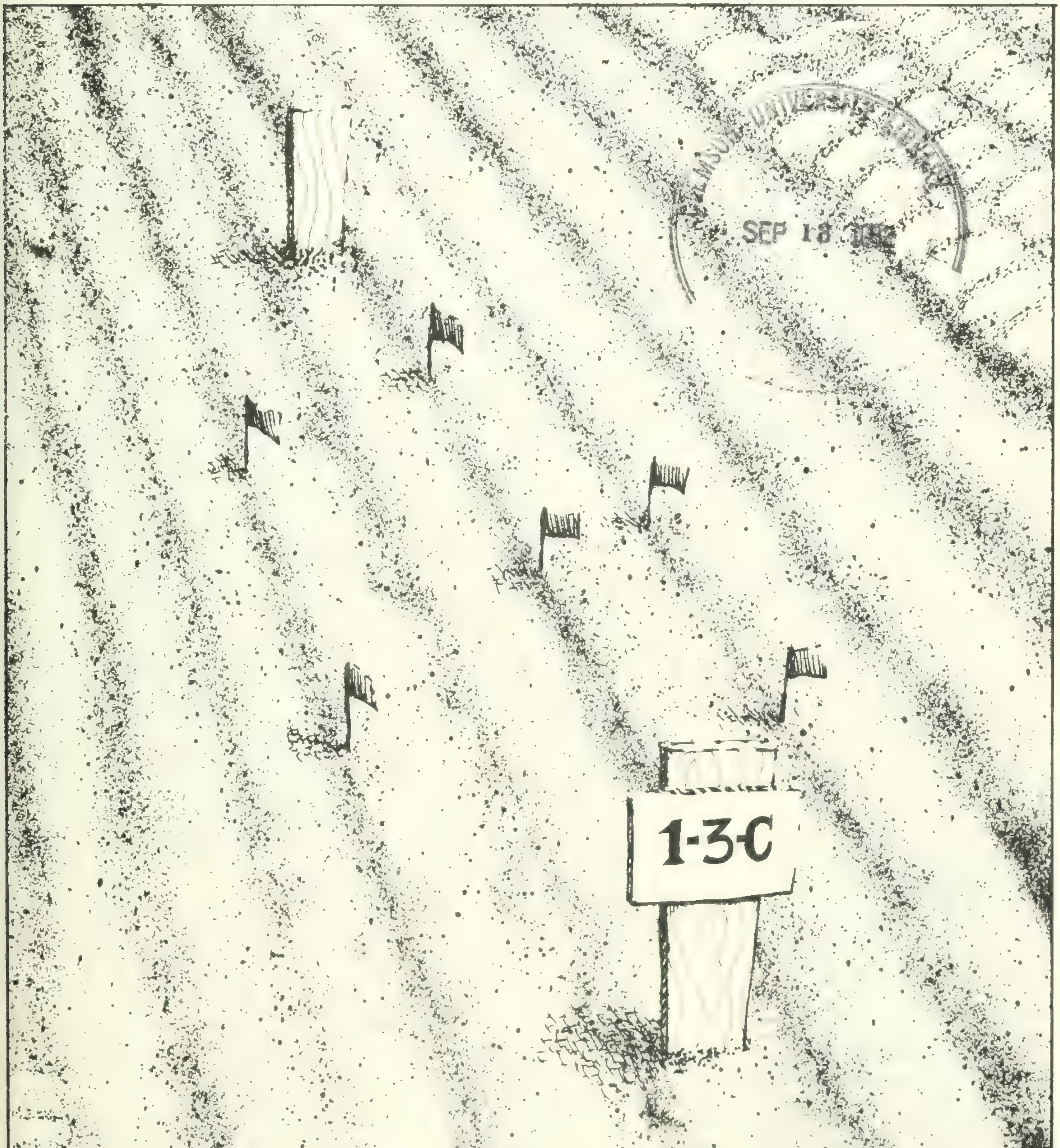
How to Test Herbicides at Forest Tree Nurseries

Roger E. Sandquist, Peyton W. Owston, and Stephen E. McDonald



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Abstract

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How to test herbicides at forest tree nurseries. USDA For. Serv. Gen. Tech. Rep. PNW-127. Pac. Northwest For. and Range Exp. Stn., Portland, OR. 1981.

Procedures developed in a cooperative westwide study of weed control in forest tree nurseries are described in a form modified for use by nursery managers. The proven, properly designed test and evaluation methods can be used to generate data needed for evaluation and registration of herbicides.

Keywords: Nursery methods, herbicides (nursery), weed control (nursery), pesticide registration.

Pesticide Precautionary Statement

Pesticides used improperly can be injurious to people, animals, and plants. Follow the directions and heed all precautions on the labels.

Store pesticides in original containers under lock and key—out of reach of children and animals, and away from food and feed.

Apply pesticides so they do not endanger humans, livestock, crops, beneficial insects, fish, and wildlife. Do not apply pesticides when there is danger of drift, when honey bees or other pollinating insects are visiting plants, or in ways that may contaminate water or leave illegal residues.

Avoid prolonged inhalation of pesticide spray or dust; wear protective clothing and use protective equipment if specified on the container.

If your hands become contaminated with a pesticide, do not eat or drink until you have washed. In case a pesticide is swallowed or gets in eyes, follow the first-aid treatment given on the label, and get prompt medical attention. If a pesticide is spilled on skin or clothing, remove clothing immediately and wash skin thoroughly.

NOTE: Some States have restrictions on the use of certain pesticides. Check your State and local regulations. Also, because registrations of pesticides are under constant review by the Federal Environmental Protection Agency, consult your county agricultural agent or State extension specialist to be sure the intended use is still registered.

Common Measures and Metric Equivalents

1 foot	0.305 meters
1 pound, avoirdupois	0.454 kilogram
1 pound/acre	1.12 kilograms/hectare
1 ounce	29.6 milliliters
1 pint	0.473 liter
1 quart	0.946 liter
1 gallon, United States	3.785 liters

Contents

əsting Herbicides at orest Tree Nurseries

-ırbicides should be tested at forest e nurseries for three major reasons:

1 *Effective use of herbicides in an egrated pest management program ch lower tree prices by reducing sts of hand and mechanical eding.*

In 1969, at the USDA Forest Service Nrsery in Coeur d'Alene, Idaho, hand-weding costs were reduced 75 pcent by using one herbicide, dihenamid, in a marginally effective wy (McDonald et al. 1974). The Cooperative Western Nursery Weed Cntrol Study,[1] has led to registration of three new herbicides since 1976 and shwn that 80 percent or more of weds can often be controlled. Work by he Auburn University Forest Chmicals Cooperative has led to reistration of seven herbicides (Girstad et al. 1978), and South et al. (198) estimate that use of effective hepicides will save $250,000 per year in eed-control costs in forest nuseries of the southeastern United Stes alone.

2. *se of herbicides at tree nurseries is small market, so those who opate nurseries must often collect the own data for registration rather tha depend on chemical companies.*

Be re they can be used, herbicides mut be registered in the geographic are in which a nursery is located. Reistration is based on performance dat that come from well-planned and coructed field tests. Since the potential or sales in the tree nursery market is sall, there is little incentive for chenical companies to develop the neeed data, and the tree nursery indstry will normally have to do this for self. The data must be collected in a ay that produces sound information in a standard, proven way.

[1] Stear, R. E., S. McDonald, and L. Abramson. 1976. An Administrative Stud for Herbicide Screening and Weed Conbl Demonstration in Western Forest Tree urseries 1976-1980. Pacific Nortwest Forest and Range Experiment Statn, Corvallis, Oreg. (unpublished).

Studies have isolated only a few herbicides and treatments that are safe and effective in nursery seedbeds. In the Cooperative Western Nursery Weed Control Study, for instance, herbicides were tested at only a few application rates and times. Because of limited time available, only chemicals found safe and effective by the highest standards were retained in the study; all others were quickly discarded. Much more work is needed to refine information about other potentially useful herbicides or combinations of products.

The broadest possible arsenal of herbicides should be established and maintained, as repeated applications of the same or similar chemicals may generate resistant weed populations. Also, since total use of an herbicide in tree nurseries involves small amounts compared to general agriculture, changes in the agricultural-use market can result in discontinuing production. With only a few chemicals to choose from, a nursery manager can be left without an effective alternative.

3. *It is good business to determine the safety and effectiveness of an herbicide at each nursery prior to operational use because each nursery has a different mixture of tree and weed species, soil and climatic factors, and cultural practices.*

Even if a potentially useful chemical is registered for herbicide use, nurseries should test it prior to use on a large scale. Each nursery situation is slightly different, and the chemical's performance may vary from nursery to nursery. On-site experience with, and confidence in, a given chemical is developed through testing. Also, testing can allow tailoring application rates and timing to more precisely fit the nursery's conditions. This paper describes a method to do the testing. It should guide those who engage in herbicide testing and encourage and expedite such work at the nurseries.

Herbicide Selection

Under the Federal Insecticide, Fungicide and Rodenticide Act, administered by the U.S. Environmental Protection Agency, it is legal to use any pesticide (herbicides are pesticides) in one of two ways. First, pesticides may be used according to their label directions and precautions. This means that use-pattern, site, and target pest appear on the label, with directions and precautions which pertain to a particular situation. *Or, the pesticide label is written in such a manner that a prudent person can interpret it to include his/her proposed use-pattern.*

Secondly, pesticides may be used under experimental permits issued by State pesticide regulatory agencies or the U.S. Environmental Protection Agency. In these instances, a pesticide is obtained from and used under the general direction of a representative of the chemical manufacturer, who is usually the person to whom the experimental permit is issued. Details and assistance can be obtained from USDA Forest Service pesticide specialists, State pesticide regulatory personnel, or technical representatives of the chemical manufacturer. The objective of testing is to find safe herbicides which control weeds economically while not adversely affecting the seedlings produced.

If restricted-use herbicides are used, the applicator or supervisor must be certified. Certification usually requires training plus passing a written test. Information on the certification of applicators is available from the USDA Forest Service or Cooperative Extension Service.

Various factors must be considered when selecting herbicides to test. These include the weed species to be controlled and the crop species to be grown. Read pertinent publications, contact colleagues in the forest and ornamental tree nursery industry to learn of their experiences with particular products. Seek the advice of chemical company technical representatives. Most companies want to be involved from the beginning, because this helps them understand your problems and objectives and how their products may be useful to you.

f problems with weed control or phytotoxicity arise, the company's familiarity with its product may hasten solutions. The company will provide information on previous screening studies, weed species controlled, and phytotoxicity and performance of the product under various climatic and soil conditions. Tests may have limited benefits if companies are uninterested or if their products are to become unavailable in the near future.

Realistically, it should not be necessary to test more than one or two new chemicals or combinations at a time. Large-scale tests such as the Cooperative Western Nursery Weed Control Study have already screened the bulk of available chemicals, and new ones should not appear on the market often. Furthermore, too many treatments can make a study too large.

General Scheme

A minimum test takes 2 years. The 1st-year's effort consists of treating small plots to carefully screen one or more chemicals, dosages, and/or application times. Although weed control is evaluated, the emphasis is on investigating phytotoxic effects. During the 2d year, herbicides showing promise are tested in somewhat larger plots to better assess economic benefits and further insure that unacceptable phytotoxicity does not occur. Also during the 2d year, further phytotoxicity data can be gathered from seedlings treated the 1st year (if seedlings are grown for 2 years). A 3d year of semi-operational testing is advisable if results after 2 years are not clear cut and/or if firmer economic data are desired.

Procedures described are for simple, randomized block experiments that can be readily analyzed for statistical significance. To be valid and free of bias, statistical principles of replication and randomization of treatments must be rigorously applied in designing the experiments: (1) A replication is a set of plots consisting of one plot of each treatment. Three replications are the minimum for reasonable statistical sensitivity, so resist any urge to reduce that number; (2) Each replication must be assigned to a specific plot by some process of randomization, such as using a random numbers table. Randomize each replication separately.

Contact a research or analytical agency, institution, or company for assistance if you want to determine such things as herbicide residue in the soil or the effects of herbicides on mycorrhizae. To save time and money, do these analyses in the 2d or 3d year if a particular treatment looked promising after the 1st year.

We have attempted to provide enough detail to permit a knowledgable nursery manager or technician to conduct the tests. Appendix 1 summarizes the procedural steps in chronological order.

First Year

Objectives.—Specific questions to as

1. Do the herbicide treatments (chemicals, dosage, and application variations) reduce seedling survival, growth, and damage rating at the end of the first growing season?

2. Do the herbicide treatments reduc the number of weeds?

Experimental design.—The basic treatment unit (plot) is a 3-foot-long sectio of nursery seedbed. Small plots such as this permit testing of a wide range of options without utilizing excessive seedbed space. This is important for minimizing the number of seedlings exposed to possible phytotoxic effects and for keeping the test small enough for a nursery to undertake.

Unless there are recommendations o experience to the contrary, test three combinations of dosage and application timing for each herbicide on eac species for which data are desired:

1. Manufacturer's recommended dosage (1X) applied within 2 days after sowing (postseeding or ps).

2. Twice the recommended dosage (2X) applied postseeding (ps) to asses effects of accidental double spraying.

3. The 1X dosage applied both postseeding and 4 to 5 weeks after emergence of tree seedlings (postgermination or pg).

In addition to the test herbicide(s) we recommend two types of control treatments for each species:

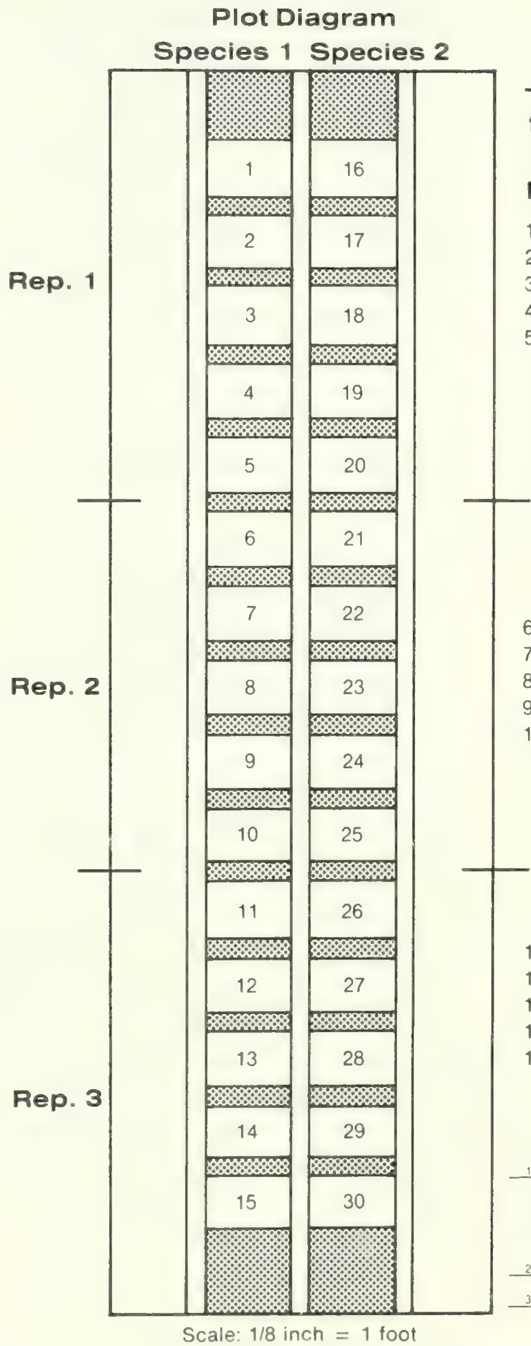
1. Untreated
2. When applicable, the standard herbicide treatment used at the nursery.

As an example, an experiment using the above five treatments with one new herbicide on two species will be described. Other combinations can be used. For instance, you might want to test more dosages and frequencies of application on a single crop species.

Te experiment described below rquires 30 plots [((3 dose-application cmbinations x 1 herbicide) + 2 chtrol treatments) x 2 species x 3 replicions]. The number of plots incases rapidly as additional hbicides and species are tested. For eample, testing three new herbicides othree species would require 99 plots. Tis, give careful thought to this section.

Pt layout.—Select two seedbeds for th test. They should be on uniform teain and in the middle beds between irigation or drainage lines. A weedy loation is desirable. One crop species w be sown per bed, and the three 5-eatment replications will be placed inhree contiguous 20-foot-long setions of seedbed. This will accommdate a 1-foot-long buffer strip beween each of the 3-foot-long plots.

Inhe office, assign species to seedbe and treatments to plots by a prcess of randomization and prepare a agram of the layout and a list of pl treatments (fig. 1). These will be usful in installing plots and maintaininreatment identity.



Treatment listing for species 1

Plot	Treatment[1]
1	Test herbicide (1X) — ps[2]
2	Standard treatment
3	Test herbicide (2X) — ps
4	Untreated
5	Test herbicide (1X) — ps + pg[3]
6	Test herbicide (2X) — ps
7	Test herbicide (1X) — ps
8	Test herbicide (1X) — ps + pg
9	Standard treatment
10	Untreated
11	Test herbicide (1X) — ps + pg
12	Standard treatment
13	Untreated
14	Test herbicide (1X) — ps
15	Test herbicide (2X) — ps

[1] List each herbicide treatment by name of chemical and rate of application (acid equivalent per acre, or ai/A)

[2] ps = postseeding application

[3] pg = postgermination application

Figure 1.—Example of plot diagram and randomized treatment listing for 1st-year screening test.

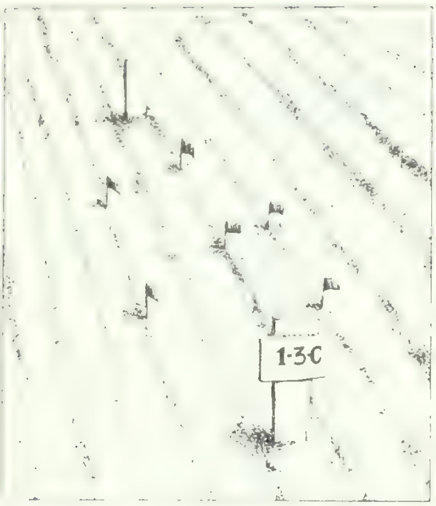


Figure 2.—Completed layout of a single 1st-year plot.

Form the seedbeds and sow the seeds. Use high quality seeds from one seed source per species or a thoroughly mixed combination of sources for each species. Lay out the plots using a steel tape for measuring and wooden stakes for marking the ends of each plot. Place stakes in the middle of beds rather than at the edges to reduce chance of their being hit by tractor wheels. Aluminum plant tags marked in advance with replication number, species, and treatment should be firmly attached to one of the stakes on each plot. Do not locate plots closer than 10 to 20 feet from either end of seedbeds. Post large signs at each end of the test area warning nursery workers not to disturb the plots.

Place two garden stakes or flagged pins 1 foot apart in each of three seeded rows per plot. Select the locations of these 1-foot subplots in a random manner, but do not place any in outside rows or within 6 inches of the ends of plots. These 1-foot subplots will be used for making seedling counts as described later.

Figure 2 illustrates the completed layout of one plot.

Herbicide application.—*Preparation of herbicide dosages.*—Prepare an herbicide mixing guide before measuring. Table 1 is an example of such a guide. Wettable powders should be weighedout in advance of treatment. Small plastic bags such as Whirl-Pak[2], 6-ounce size, are ideal for holding small amounts of wettable powders. All of the herbicide in such bags is easily rinsed into the spray solution during the mixing phase. Be sure to pre-label the bags with plot number, name of herbicide, formulation, rate of application, and amount of herbicide in grams.

[2]Mention of product or trade name does not imply endorsement by the U. S. Department of Agriculture.

Table 1—Example of herbicide mixing guide for nursery weed control trials

Herbicide	Formulation[1]	Rate	Amount Required 1 plot	3 plots	6 plots
		(lb ai/a)[2]			
bifenox	Modown 80WP	3	0.53g	1.59g	3.18g
trifluralin	Treflan 4EC	¾	0.2ml	0.7ml	1.3ml
napropamide	Devrinol 50WP	3	0.84g	2.52g	5.04g

[1]Mention of product or trade name does not imply endorsement by the U.S. Department of Agriculture.

[2]ai/a means acid equivalent per acre.

The formula for determining the amount of wettable powder in grams to treat one plot is:

$$\frac{\dfrac{\text{length of plot (feet)} \times \text{sprayer swath width (feet)}}{43{,}560\ \text{ft}^2} \times \text{pounds active ingredient per acre}}{\text{pounds active ingredient per pound of formula}} \times 458.6$$

or, for 3- x 4.5-foot plots,

$$\frac{\text{pounds active ingredient per acre}}{\text{pounds active ingredient per pound of formula}} \times 0.141.$$ [3]

Mix this amount of herbicide with 100 ml of water to obtain a spray batch equivalent to 85 gallons per acre for plots 4.5 wide x 3 feet long. Adjustments should be made if different carrier rates are recommended by product manufacturers.

The amount for all three replications of each treatment can be combined into one batch to reduce mixing and rinsing times. The amount of water would likewise be increased from 100 to 300 ml.

The small amounts of herbicide needed require a good laboratory-type balance, accurate to hundredths of a gram.

Measure out liquid herbicides at time of application using a pipet accurate to tenths of a milliliter. Use a pipet filler (not mouth suction!) for safety and convenience. The formula for determining the amount of liquid herbicide to use in milliliters is:

$$\frac{\dfrac{\text{length of plot (feet)} \times \text{sprayer swath width (feet)}}{43{,}560\ \text{ft}^2} \times \text{pounds active ingredient or acid equivalent per acre}}{\text{pounds active ingredient or acid equivalent per gallon of formula}} \times 3785$$

or, for 3- x 4.5-foot plots,

$$\frac{\text{pounds active ingredient or acid equivalent per acre}}{\text{pounds active ingredient or acid equivalent per gallon of formula}} \times 1.17.$$ [4]

[3] Re-compute for other swath-widths.

[4] Re-compute for other swath-widths.

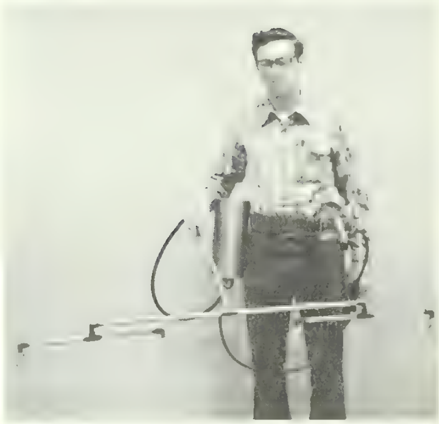
Have the herbicide mixing guide in front of you at the time of application (table 1).

Application equipment.—Good spray equipment is essential for accurate and uniform application of liquid formulations to small plots. During the Cooperative Western Nursery Weed Control Study, an AZ Small-Plot CO_2 Research Sprayer with a 4.5-foot swath width was used (fig. 3). The sprayer consisted of a 3.4-foot boom with four flat-fan nozzles. A 1-pint bottle held the chemical mixture, and pressure was supplied by a 2.5-pound CO_2 cylinder with a pressure regulator. Other sprayer configurations are available from the manufacturer: AZ Field Test Service (see footnote 2), Accord, New York.

Several modifications were necessary Stainless steel strainers (50-mesh) with check valves were installed in the nozzle assemblies. The check valves are necessary if more than one plot is to be sprayed per batch. Also, smaller nozzle tips were installed (Tee Jet (see footnote 2) size 8001 or other flat-fan nozzle of same spray angle and flow rate). The small nozzle is necessary to give enough spray time to spray each plot evenly. Stainless steel nozzle tips are recommended for longer wear. It is important to disassemble and clean the strainer and nozzles periodically and to spray the check valves with a lubricant.

A small hand-pumped pressure sprayer may be modified to perform acceptably. A 1.5-gallon stainless steel tank can be fitted with a pressure gauge. A corrosion resistant pump, funnel and shutoff, a 16-inch curved brass extension tube, and a 5-foot hose are desirable. A cap nozzle providing two overlapping flat-fan spray streams should provide a good swath.

Calibration and applications of liquids.—Calibration of the sprayer is important for applying the proper amount of spray to plots. Because the small-plot pressurized sprayer has a CO_2 pressure source plus a pressure regulating device, calibration is quick and easy. Set the pressure and time delivery of the desired volume (100 ml per plot).



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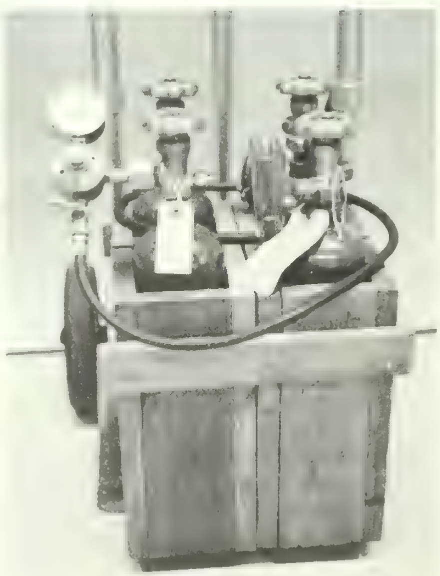

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Figure 3.—Small-plot CO_2 research sprayer: **A** Complete apparatus ready for use; **B** Bottle with spray head attached and carrying case on left; **C** Stainless steel 50-mesh strainer and check valve assembly; **D** CO_2 cylinders in transporting box (cylinders must be kept upright); **E** Adjustment of pressure regulator (see text).

Use the average of several trials as delivery time for the test application. Check nozzles periodically for clogging and uniform distribution. Our experience with the small-plot sprayer equipped as described suggests that 100 ml of spray will be applied in 5.5 seconds at 20 lb/in^2 pressure. A stop watch is necessary. One person should operate the sprayer, and a second person should time the application.

When using the small plot sprayer, it is advisable to first turn the adjusting screw on the regulator out (counterclockwise) before opening the valve on the CO_2 cylinder. Otherwise, excessive pressure may occur and damage the gauge. Open the CO_2 valve slowly to "full", then turn the adjusting screw on the regulator in (clockwise) to obtain the desired pressure. Check the pressure frequently and readjust as necessary. Do not allow the CO_2 cylinder to lie horizontal with the valve open or liquid CO_2 will enter the system and damage the regulator. Overfilled cylinders will also cause liquid CO_2 to enter the system, even when held upright. Keep cylinders out of direct sunlight when not in use.

Calibrating a hand-pump pressure sprayer is more involved. The objectives are to fill the sprayer once with enough material to spray all plots with that herbicide and to get uniform delivery at fairly low pressure, about 20 lb/in^2. This will require putting enough herbicide in the tank to spray an extra plot before application, because you won't be able to empty the tank completely. The extra can be sprayed on seedbed outside the plots. Some experimentation is necessary to develop the technique. Put 3 liters into the sprayer and pump up to about 20 lb/in^2. Time the delivery of five 100-ml portions, pumping the sprayer between each portion. If there is little variation between the times, use the average time to deliver the 100 ml. If there is variation, practice your technique until you can consistently pump the tank to deliver the 100 ml in about the same amount of time. Pump up the sprayer. Time the delivery of two 500-ml portions, pumping the sprayer between applications. Again, if there is variation, practice your technique until you can consistently apply the same volume within a given time.

Valid tests require uniform application of specific amounts of herbicide to given areas. We suggest that two persons develop the technique and apply the herbicide, one person operating the sprayer and the other doing the timing. They should know the objectives and procedures of the study. Necessary equipment and materials should be on hand, and sufficient time should be made available to do the job correctly and precisely.

Apply emulsifiable concentrates, wettable powders, and water soluble compounds in a water carrier at a volume equivalent to 85 gallons per acre (100 ml per plot). Spray one-half the volume in each of two passes over the plot in opposite directions. Apply all herbicides on the same day under as calm conditions as possible. Irrigate thoroughly afterwards to wash chemicals into the soil. Apply post-seeding treatments within 2 days after seeding and postgermination treatments 28 to 35 days after emergence of crop seedlings. Consider emergence to be the time when most seedlings have shed their seedcoats.

In addition to insuring good calibration, it is critical to avoid contaminating herbicide treatments. The fewer times a sprayer has to be filled with different herbicides, the less chance there is for contamination or error. Thus, it is best to spray all the plots of one herbicide before turning to another.

Cleaning application equipment.—Between uses of different herbicides, rinse all parts of the sprayer completely with water, clean with a mixture of strong detergent and ammonia, and rinse again thoroughly with water. Take care not to damage the finely machined surfaces of the nozzle tip. Clean them using a soft brush, not a knife, wire, or other hard material. Replace a nozzle when it is damaged. Spray rinsings on a non-crop area, preferably where some weed control could be gained from the residual herbicide.

Choose your cleaning area with great care. It is important to discharge the cleaning water where it will not contaminate water supplies, streams, crops, or injure other plants, and where puddles will not be accessible to children, livestock, pets, or wildlife.

Application of granular herbicides.—Apply granular herbicides with a shaker device. Ocularly divide the plot into quarters and apply one-fourth of the herbicide on each quarter.

If the material must be incorporated into the soil prior to seeding, the plots must be laid out in advance and the chemical applied no more than 1 day before seeding. Incorporate the material into the top 2 inches of soil with a garden rake. Reshape and compact the ground surface to conform to the rest of the seedbed.

Records.—Be sure to follow the diagram and plot tags when applying treatments, and record any deviation which occurs by mistake. Record date of application, weather conditions, and any events or situations you feel may affect the results.

Plot maintenance.—Conduct all other nursery operations such as irrigation, fertilization, and undercutting as needed and as uniformly as possible. Maintain a record of the operations and dates of application.

Data collection. *Weed control.*—Hand-weed all plots about 26 to 34 days after tree seedling emergence but 1 to 2 days prior to application of post-germination treatments. In addition, hand-weed all plots as needed beginning 1 month after postgermination application. Base needs for weeding on the most weedy plot or plots, and weed all plots in each replication on the same day to avoid differences resulting from additional weed growth. Do not water during the 24 hours preceding weeding.

For each weeding, separate weeds from individual plots into grass and forbs, count the number in each group, and identify the major species (appendix 2). Summarize data on numbers at the end of the season (appendix 3).

Phytotoxicity.—To assess the effects of treatments on seedling emergence and survival, count the number of seedlings between the two stakes that were placed 1-foot apart in three rows of every plot. Do this about 25 days after seedling emergence and at the end of the first growing season (appendix 4).

Rate the damage to crop seedlings at the time of postgermination application and at the end of the first growing season using the following rating system (appendix 4):

Damage rating system for crop seedlings (adapted from Anderson 1963)

Rating	Description
10	No damage.
7-9	Slight damage; seedlings will recover and make near normal growth.
4-6	Moderate damage; few seedlings have died but some show chemical effects and reduced growth.
1-3	Severe damage; many seedlings have died; others are discolored and stunted.
0	All seedlings dead.

It is unlikely that different people rate seedlings exactly the same. To provide consistency, a single individual should do all the rating at a nursery. In addition, that person should briefly describe and record specific factors used to determine ratings.

At the end of the first growing season, measure height of all seedlings between the three sets of stakes used to determine survival in each plot (appendix 5). Also, dig a few seedlings from each plot and examine them closely for abnormal growth characteristics that might not appear in the quantitative data, such as stem swelling (Stewart et al. 1978) or lack of root branching.

Summarize survival, damage (appendix 6), and height data (appendix 7).

Data analysis.—As a minimum, determine sums and means (averages) of the numerical data for each treatment: total number of weeds by type for each weeding and the season; number of crop seedlings per foot; crop seedling height; and damage rating. Pool (combine) all of the weed control data for the nursery if the same treatments were used for each species, but keep the crop measurements separated by species.

For easier comparison, convert the data to percentages of effect, using the untreated control as the base of 100 percent.

The data should also be analyzed statistically by analysis of variance and some test of individual treatment comparison to make sure that differences are due to treatment rather than chance. Although the mechanics can be done relatively easily on modern programable calculators or computers, it is not advisable to attempt an analysis without knowledge of statistical concepts. Seek the help of someone with training in statistics if such expertise is not available at the nursery. The formats for an analysis of variance of the test example using one herbicide, two species, and three replications are:

Weed control data (pooled by species)

Source of variation	Degrees of freedom
Treatments	4
Replications	5
Error	20
Total	29

Phytotoxicity data (for each species)

Source of variation	Degrees of freedom
Treatments	4
Replications	2
Error	8
Total	14

Use Tukey tests to compare individual treatment differences.

Subjectively examine the information on weed species to determine whethe[r] herbicides differ in their species selectivity.

Interpretation of the results involves examination of the data and analyses and consideration of test conditions and observations — in other words, a combination of facts, logic, and common sense. For assistance, stud[y] published reports of similar experiments (Steward 1977 and Stewart et a[l.] 1978).

If one or more herbicides or specific combinations of herbicide and application rate appear promising in this initial test, conduct a larger scale trial the 2d year. Firm guidelines cannot be given for deciding what treatments warrant further testing. Each nursery manager must decide o[n] the basis of weed control objectives, costs, and effects on crop seedlings. In the Cooperative Western Nursery Weed Control Study, further testing was generally done for treatments tha[t] gave at least 70-percent weed control and resulted in an average damage rating no more than 10 percent less than that of untreated seedlings (Steward 1977).

Second Year

Objectives.—The objectives of the 2d-year test are to further evaluate the effectiveness and safety of herbicide treatments identified as promising in a 1st-year test. Specific questions to be asked are:

1. Do the herbicide treatments reduce the time required to hand-weed 1st-year nursery beds?

2. Do the herbicide treatments reduce conifer crop seedling survival, growth, and damage rating at the end of the first growing season and shoot length and condition at the end of the second growing season?

Experimental design.—The plots will be 20 feet long. Treatments to test are those that, in the previous year's testing, equaled or exceeded results from the current standard treatment and untreated controls.

For example, assume that the previous year's test herbicide, applied post-seeding (1X dose), performed slightly better than the standard herbicide treatment. This year's test will consist of three treatments — 1X dose of test herbicide applied postseeding, standard nursery treatment, and an untreated control. This will be done on the same two species as before. Eighteen plots will be needed (three treatments x three replications x two species).

Plot layout.—Lay the plots out the same as the 1st year but increase plot size to 20 feet. This will require 188 feet of seedbed for each of two species.

Herbicide application.—Prepare and apply herbicide in the same way and with the same schedule as before, but use the amount needed to cover the larger plot size, and use a 1-quart bottle for the small-plot sprayer rather than the 1-pint size. A hand-pumped pressure sprayer is probably unworkable for this size of plot. Clean equipment as described for the 1st-year test.

Use the same formula as before. Amounts of wettable powder (grams) and liquid (milliliters), respectively, to apply to plots 4.5-feet x 20-feet are:

$$\frac{\text{lb ai per acre}}{\text{lb ai per lb of formula}} \times .937 = \text{grams of wettable powder}^{5/}$$

$$\frac{\text{lbs ai or ae per acre}}{\text{lbs ai or ae per gallon formula}} \times 7.82 = \text{milliliters of solution}^{5/}$$

Records and plot maintenance.—Conduct these tasks as in the 1st year.

Data collection. *Weed control.*—Conduct weeding as before, but, in addition, carefully measure and record the time required to weed each plot (appendix 8). Identify the weed species (appendix 2), but do not bother to count them this year.

Phytotoxicity.—Collect and record damage rating and growth data as before for the 1+0 seedlings (appendices 4-7). In addition, lift 10 randomly selected 2+0 seedlings from each plot in the 1st-year test that received the same treatment the 2d year. Collect and record the same growth and condition information (appendices 4-7).

[5] Recompute for other swath widths.

Data analysis.—Follow 1st-year procedures. Analysis of variance tables for the test example of two herbicide treatments and an untreated control on two species are:

Weed control data (pooled by species)

Source of variation	Degrees of freedom
Treatment	
Control vs. test herbicides + standard	1
Test vs. standard	1
Replications	5
Error	10
Total	17

Phytotoxicity data (for each species)

Source of variation	Degrees of freedom
Treatments	
Control vs. test herbicide + standard	1
Test vs. standard	1
Replications	2
Error	4
Total	8

Third Year (optional)

Objectives.—A 3d-year test may be advisable to provide a greater margin of safety, yield better economic data, and demonstrate levels of weed control under semi-operational conditions. If previous results were not clear-cut, 2-year-old seedlings may also be sampled for growth.

Semi-operational tests should be coordinated through the potential registrant of the herbicide to assure that all requirements for Experimental Use Permits and other requirements are met.

Two specific questions will be asked:

1. Do the herbicide treatments reduce the time required to hand-weed 1st-year nursery beds?

2. Do the herbicide treatments reduce crop seedling survival (optional), growth, and damage rating?

Experimental design.—The basic treatment unit (plot) is a 200-foot-long section of nursery seedbed. Plots this large permit use of regular nursery spraying equipment and provide enough space to accurately assess total crew time required for hand weeding. The first 2 years have presumably eliminated any treatments that are phytotoxic to the crop species.

Treatments to use are:

1. Applications identified as promising in the first 2 years of testing (the best or a few of the best combinations of herbicide and application timing).

2. Untreated control.

3. Standard nursery treatment (if applicable).

Again, use a minimum of three replications of each treatment in a randomized block design. That is, install a complete set of treatments (one plot of each in adjacent seedbeds) in three places in the nursery. At this point in the testing program, phytotoxicity of the herbicides should have been established. Any species for which phytotoxicity data is still wanted, however, must be represented in each plot. It is safe to assume that weed control characteristics of the herbicides will not vary with crop species.

The example will consist of three replications of three treatments: (1) postseeding plus postgermination applications of one herbicide; (2) an untreated control; and (3) the standard treatment. This will require nine 200-foot-long plots.

Plot layout.—Select three sets (replications) of three seedbeds each for the test. Use the same seedlot(s) of the crop species within a replication. As before, assign treatments within each replication to plots in a random manner and prepare a diagram of the layout.

Form the seedbeds and sow the seeds on a single day. Lay the plots out using a steel tape and wooden stakes. Avoid using the first or last 10 to 20 feet of any seedbed. Attach treatment identification to one of the stakes of each plot, and post large signs at each end of the test area.

Placing sets of wire pins, as done the 1st and 2d years to mark subplots for seedling counts, is optional.

Herbicide application. *Preparation.*—It is not feasible to spray the exact amount of herbicide for the 200-foot plots; application should begin before the operator reaches the beginning of the plot and extend somewhat beyond the end of the plot to ensure uniform application over the full length. Furthermore, most sprayers can't maintain uniform pressure as the tank approaches the empty point. Thus, the approach should be to adjust the tractor speed to evenly dispense the correct amount of herbicide on the plots.

In advance of treatment, weigh or measure the amount of herbicide needed for the test plots plus one extra plot. Use the same formula as before:

$$\frac{\dfrac{\text{200 ft x spray swath width (feet)}}{\text{43,560 ft}^2} \times \text{pounds active ingredient per acre}}{\text{pounds active ingredient per pound of formula}} \times \text{453.6 grams o wettable powd per plot.}$$

or

$$\frac{\dfrac{\text{200 ft x spray swath width (feet)}}{\text{43,450 ft}^2} \times \text{pounds per active ingredient or acid equivalent per acre}}{\text{pounds active ingredient or acid equivalent per gallon formula}} \times \text{3785 milliliters of liquid herbic per plot.}$$

Application equipment.—Use the spray equipment normally employed at the nursery. Some temporary modification, such as blocking nozzles, may be necessary to adjust the swath width to cover only a single seedbed. For convenience, mix enough for four plots at one time.

Manufacturers of granular herbicides should be able to recommend equipment for spreading their products evenly.

Calibration and application of liquids.—Apply herbicides in water at a volume equivalent to 50 gallons per acre. This amount is equal to:

$$\frac{\text{200 ft x swath width (feet)}}{\text{43,560 ft}^2} \times 50 = \text{gallons per plot.}$$

Using plain water, determine how much time it takes for the sprayer to dispense the required volume for a plot. Use the average delivery of nozzles to be employed, cleaning or replacing nozzles that vary more than 10 percent from the average. Spray cups may be used to catch the spray over a given period of time and compare it with the amount of water delivered. Then drive the tractor at a speed which will cover the 200 feet in that length of time (table 2). Practice on 200 feet of unsown beds or roadway, using the appropriate swath-width.

Table 2—Times needed to travel 200 feet at specific tractor speeds

Speed (m/h)	Time to travel 200 feet (s)
0.50	273
0.75	182
1.00	136
1.25	109
1.50	91
1.75	78
2.00	68
2.25	60
2.50	54
2.75	49
3.00	45
3.25	42
3.50	39
3.75	36
4.00	34
4.25	32
4.50	30
4.75	29
5.00	27

.pply all herbicides on the same day, nder conditions as calm as possible. igate thoroughly afterwards to wash e chemicals into the soil. Apply stseeding treatments within 2 days ter seeding, and postgermination eatments should be applied 28 to 35 ys after emergence of crop edlings.

 speed operations and avoid ntamination, spray all plots ceiving the same herbicide before ing another chemical.

eaning of equipment.—As before, id contamination between rbicides by thoroughly rinsing the k, boom, and nozzles. Rinse once h plenty of plain water, a second e with water and a commercial tank sing compound, and a third time h plain water. As before, dispose of rinse water where it will not taminate water supplies, streams, ps, or injure other plants, and ere puddles will not be accessible hildren, livestock, pets, or wildlife.

 following steps are suggested for rough cleaning:

1. lose down the inside of the tank ompletely, filling it half full of ater. Then flush the cleaning water rough the nozzles by operating the prayer.
2. epeat the procedure in step 1.
3. emove nozzle tips and screens. lean them in kerosene or detergent olution, using a soft brush. Do not se a knife, wire or other hard aterial to clean nozzle tips. The nely-machined surfaces of the tips an be easily damaged, causing distortion of the spray pattern and an creased rate of application.
4. ll the tank about half full of water d add about 1 pound of detergent r every 50 gallons of water.
5. Operate the pump to circulate the detergent solution through the sprayer for about ½ hour, then flush it out through the boom.

If you have used 2,4-D or an organophosphorous insecticide, before doing step 6, follow this additional procedure:

a. Replace the screens and nozzle tips.

b. Fill the tank about half full of water and add 1 pint of ammonia for every 25 gallons of water.

c. Operate the pump to circulate the ammonia solution through the sprayer for about 5 minutes, and discharge a small amount through the boom and nozzles.

d. Keep remaining solution in the sprayer overnight.

e. In the morning, flush out all the ammonia solution through the nozzles by operating the sprayer.

6. Fill the tank about half full of clean water while hosing down both the inside and outside, then flush out through the boom.

When finished with the sprayer for the season, remove the nozzle tips, strainers, and screens and store them in light oil. Store the sprayer in a clean, dry shed. If the pump cannot be drained completely, store it where it cannot freeze.

Records.—Be sure to follow the diagram and plot tags when applying treatments, and record any deviation occuring by mistake. Record date of application, weather conditions, and any events or situations you feel may affect the results.

Plot maintenance.—Conduct all other nursery operations such as irrigation, fertilization, and undercutting as needed and as uniformly as possible. Maintain a record of the operations and dates applied.

Data collection. *Weed control.*—Hand-weed all plots about 26 to 34 days after crop seedling emergence but 1 to 2 days prior to application of postgermination treatments. Hand-weed all plots as needed beginning 1 month after postgermination application. Base need for weeding on the most weedy plot or plots, and weed all plots on the same day to avoid differences in weed growth. Do not water during the 24 hours preceding weeding.

Record the total time needed to hand-weed each plot (appendix 8). Since times will be compared, have the same crew do all the weeding within each replication on the same day. If possible, keep conditions similar between replications as well. Do not include break times. Summarize the effects of herbicides on time needed for hand-weeding as in appendix 9.

Identify weed species in each plot prior to each weeding and subjectively classify them into one of three categories of abundance — low, medium, high.

Phytotoxicity.—Use the damage rating system described for the 1st-year test. At the end of the growing season make observations in 1-foot-long samples every 20 feet along the test seedbeds (appendix 10).

Also at the end of the growing season, measure length of main stems of three random groups of 10 seedlings in each plot (appendix 4). Summarize as in appendix 7. Make seedling counts if desired (appendix 3).

Data analysis.—Follow the general procedures described for the 1st year. Numerical data for the 3d year consist of: (1) time needed for each weeding and total season, (2) crop seedling heights, (3) and damage rating.

Analysis of variance tables for the example have the following form:

Weed control and phytotoxicity

Source of variation	Degrees of freedom
Treatment	
Control vs. test herbicide + standard	1
Test vs. standard	1
Replications	2
Error	4
Total	8

How to Use the Acquired Information

As stated in the introduction, one of the reasons to test herbicides in forest tree nurseries is to obtain data to support registration of useful herbicides. To be useful, the data must meet requirements of both chemical companies and registration. The method offered here satisfies all current requirements, but changes might invalidate a subsequent study. It is important to keep in contact with representatives of the chemical company whose products you are investigating. Also, knowledge of testing that other nurseries are doing gives you and the chemical company representative a basis for comparing results if testing is done similarly. The first year's data, while not usually adequate for registration of a product, will indicate whether testing should be continued a second year. Chemical company representatives, USDA Forest Service Pesticide Specialists, Cooperative Extension Service personnel or others can assist in making these determinations. The data developed may supplement information from other nurseries and may help achieve registration.

It is important to have all data available and summarized shortly after the field season so if the data support use, the chemical company can seek registration and have the herbicide available for the next field season. It takes 3 months to a year to get a use registered once the data are available. Since the company may be working with several nurseries, progress will depend upon information from the last nursery to report. Examples of forms useful for summarizing data are found in appendices 3,6,7, and 9.

The chemical company will analyze the data to see whether it is interested in registering its product for forest tree nursery use. Standards of performance must be met before companies are interested in pursuing specialty uses. One of the prime considerations is liability. If there is not an adequate margin of safety for crop seedlings, a company may not wish to register the product. In most instances, however, if a nursery manager is satisfied the product is safe, the chemical company will be also.

We cannot stress too strongly that information developed should be given to chemical companies as soon as possible, because they are usually the ones to initiate registration of the products.

The information developed in your test should also be shared with your colleagues. This can be done informally, but presentation at nursery managers' meetings or in written publications will allow a greater dissemination of your work. Communication with others may lead to greater standardization or innovative methods to make the job easier.

afety in Pesticide Use

n though amounts of herbicide d in tests are small compared with rational use, follow safe practices. certain that persons using ticides are competent and trained. ining assistance can be requested esticide or nursery specialists of USDA Forest Service or technical resentatives of the chemical panies. Training should include:

escription of known potential an health effects anticipated from osure to each herbicide.

2. rocedures for mixing and applying bicides and cleaning equipment.

3. rocedures for storing and osing of unused herbicides and residue in rinse materials.

Summary

This report describes a proven way of identifying herbicides that are safe and effective in controlling weeds in forest tree nursery seedbeds. The design, equipment, methodology, and analysis techniques are given for testing herbicides for postseeding and postgermination weed control and phytotoxicity. Weed control techniques in the nursery need to be refined. The approach presented here can be modified to test any number of applications of herbicides to seedbeds. Testing is encouraged, as innovation must come from individual nurseries. Proper documentation of new approaches or new herbicides, plus timely and open communication with colleagues, pesticide specialists, and chemical companies can result in further advances in nursery weed control.

Acknowledgments

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Appendix 1

Summary of study procedures for each year in chronological order

1. Certify the applicator or supervisor.
2. Select treatments and acquire herbicide(s) and other supplies (winter).
3. Prepare dry herbicides for mixing (early spring).
4. Diagram plots in office and randomly assign treatments to plots (early spring).
5. Form seedbeds and sow seeds (spring).
6. Lay plots out on ground (spring).
7. Calibrate sprayer (spring).
8. Apply postseeding treatments (spring).
9. Hand-weed plots and record data (late spring).
10. Apply postgermination treatments (late spring).
11. Hand-weed as necessary and record data (late spring and all summer).
12. Collect seedling counts, heights, damage ratings, and weights (fall).
13. Analyze data and make plans for next year (fall and/or winter).

Appendix 2

Weed control data for nursery herbicide test — 1st and 2d years (data form)

Nursery ______________________________ Crop species ______________________________

Seedbed location ______________________________ Date ______________________________

Plot no.	Treat.	Grass		Forbs	
		No.	Species1/	No.	Species1/

1/ Amount of detail concerning individual species is flexible. The objective is to determine species selectivity of the herbicides.

ppendix 3

/eed control for nursery herbicide test — 1st and 2d years[1] (summary)

ursery ______________________________ Year______________

Treatment	Weed numbers			
	First weeding	Subsequent weedings	Total season	Percent of untreated
Untreated				100

[1] Weed control ratings shown are the means of all plots of each treatment. Number of weeds are expressed as percent of the untreated plots (average divided by average of untreated x 100).

Appendix 4

Crop-seedling survival and damage data for nursery herbicide test (data form)

Nursery ______________________ Crop species ______________________

Seedbed location ______________________ Year ______________________

Plot no.	Treatment	No. seedlings/foot (Date________)			Damage rating
		1	2	3	(Date________)

Appendix 5

Crop seedling height for nursery herbicide test (data form)

Nursery ______________________________ Crop species ______________________

Seedbed location ______________________ Date sown ______________________

Treatment ____________________________ Date sampled ______________________

Plot ________	Plot ________	Plot ________
	mm	
Total		
Mean		

Grand total ________ mean ________

Appendix 6

Crop-seedling damage and survival data (summary)

Nursery ______________________________ Year ______________

Treatment	Species ______		Species ______	
	Ave. damage rating	Survival (% of untreated)[1]	Ave. damage rating	Survival (% of untreated)[1]
Untreated		100		100

[1] Percents are found by dividing the average rating for each treatment by the average for untreated plots and multiplying by 100.

pendix 7

ffects of herbicides on growth of crop seedlings (summary)

Treatment	Height (mm)	
	Species_______________	Species_______________

Appendix 8

Time needed to weed plots — 2d and 3d years (data form)

Nursery ______________________________ Crop species ______________________

Seedbed location ______________________________ Date sown ______________________

Date	Plot no.	Treatment	(1) Crew size (no.)	(2) Crew weeding time (min. & sec.)	(1 x 2) Total weeding time (min. & sec.)

Appendix 9

Effect of herbicides on hand-weeding — 2d and 3d years[1] (summary)

Herbicide	Timing	Rate	First weeding	Subsequent weedings	Total season	Percent of[2] untreated
		(lbs ai/acre)	*Minutes*	*Minutes*	*Minutes*	*Percent*
untreated						100

[1] Times shown are the mean number of person-minutes to weed a 200-foot-long plot.
[2] Percents are found by dividing the total season weeding times for each treatment by the weeding time for untreated plots and multiplying by 100.

Appendix 10

Crop seedling damage rating — 3d-year (data form)

Nursery ______________________ Crop species ______________________

Seedbed location ______________________ Date ______________________

Sample point[1/]	Plot ______ Treatment ______	Plot ______ Treatment ______	Plot ______ Treatment ______	Plot ______ Treatment ______	Plot ______ Treatment ______
			Damage rating		
20					
40					
60					
80					
100					
120					
140					
160					
180					
Total					
Ave.					

[1/]Twenty-foot intervals along 200-foot plots.

Sandquist, Roger E., Peyton W. Owston, and Stephen E. McDonald.
How to test herbicides at forest tree nurseries. USDA For. Serv. Gen. Tech. Rep. PNW-127. Pac. Northwest For. and Range Exp. Stn., Portland, OR. 1981.

Procedures developed in a cooperative westwide study of weed control in forest tree nurseries are described in a form modified for use by nursery managers. The proven, properly designed test and evaluation methods can be used to generate data needed for evaluation and registration of herbicides.

Keywords: Nursery methods, herbicides (nursery), weed control (nursery), pesticide registration.

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